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REPORT ON THE MOSQUITO INVESTIGATIONS.

November 29th, 1902.

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REPORT ON THE MOSQUITO INVESTIGATIONS.

JOHN B.ernhard SMITH, SC.D.

By an act of the Legislature of New Jersey, passed at its session during the early months of 1902, and duly approved by the Governor, the Agricultural Experiment Station was "empowered and directed to investigate and report upon the mosquitoes occurring within the State; their habits, life history, breeding places, relation to malarial and other diseases, the injury caused by them to the agricultural, sanitary and other interests of the State, their natural enemies, and the best methods of lessening, controlling or otherwise diminishing the numbers, injury or detrimental effect upon the agricultural, sanitary and other interests of the State."

The law was not passed until late in the session, and no money was provided to carry it into effect. It was due entirely to the appreciation by Governor Murphy of the importance of the investigation that any work at all was possible, and he promptly placed at the disposal of the Station the sum of $1,000 from an emergency fund within his control.

The writer of this report was appointed to make such studies as were possible under the circumstances, and work was begun late in May, after the mosquito season was already well started. Fortunately, the work done by me during 1900, which was detailed in the Report of the Agricultural College Experiment Station, served as an introduction to this investigation, and enabled me to secure results that would have been otherwise impossible.

It will be realized that a problem so extensive in scope as is outlined in the act above referred to cannot be solved in any one year, with so limited an amount of money at hand. All that could be done was to start the work and to ascertain as fully as possible the direction in which future investigations would be likely to be most fruitful.

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This, then, must be considered as a report of progress merely and as a narrative of what investigations were started.

It was realized that when the exact role of certain species of mosquitoes, in carrying or transmitting the disease organisms causing malarial fevers, was once thoroughly understood, the matter of dealing with such mosquitoes would be merely an extension of the sanitary work already in charge of boards of health, local and general; hence, I secured the services of Dr. Herbert P. Johnson, who had paid much attention to these studies, had served as an assistant in the Harvard Medical School and had also worked with Dr. Theobald Smith in the laboratory of the Massachusetts State Board of Health. A conference was had with Dr. Smith early in June, and Dr. Johnson began his work in New Jersey soon after July 1st, in quarters placed at his disposal by the Harrison Board of Health. Grateful acknowledgment is due to this board and to its members and their inspector for this and other courtesies extended.

Dr. Johnson continued his work until September 20th, and his account of what was accomplished forms a supplement to this report. It should be added that Dr. Johnson turned over to me on September 19th a very lively lot of hungry *Anopheles* mosquitoes, and that on the 24th of that month they were treated to a meal of blood from a patient suffering from malaria. The specimens were later examined by Dr. W. N. Berkeley, of New York City, but no definite results were obtained. We have no positive evidence to prove that our most common species of *Anopheles punctipennis* can act as an intermediate host for the malarial disease parasite; but against the other, *A. maculipennis,* the case is definitely proven. On this point and on the breeding habits of *Anopheles,* Dr. Johnson's report should be consulted.

The subject of the natural enemies of mosquitoes is of much greater importance than is generally realized. They need water in which to pass their early stages, and almost any kind will answer for some species. That large bodies of water do not necessarily mean large numbers of mosquitoes is a matter of common experience, and the natural question is, why is that the case? To answer this it becomes necessary to study the fauna of those places where the insects breed and larvæ are found, in comparison with those places in which they do not breed and where no larvæ are found. It is desirable to know, also, whether any of the smaller birds make use of the adults as food to any considerable extent.

This branch of the work was placed in general charge of Mr. William P. Seal, of Delair, N. J., formerly in the service of the United States Fish Commission and thoroughly acquainted with the fresh-water fauna in this section of our State. His observations are reserved for the present and will be used in the final report, to indicate the lines upon which such work must be conducted. It was hoped that it might be possible to secure the co-operation of the Fish and Game Commission of the State in the study of some of the other vertebrate enemies of the mosquito, but up to this time the effort has not been successful.

A simple observation made during midsummer will illustrate the importance of the subject. Two water barrels, close to a farm-house, became very full of wrigglers. The boy of the house, who had been somewhat interested in the subject, caught a small roach in a pond nearby and placed it in one of the barrels. In a remarkably short time, not a wriggler was left, and when the fish was transferred to the other barrel that also was cleared. Cisterns, therefore, or water barrels need only a few examples of these little fish, that occur all over our State, to make them perfectly safe. As there would be no natural nemies, even a single little fish would last out an entire season.

Another practical illustration comes in a nursery where water plants are raised in large numbers in ponds, tubs, basins and receptacles of all kinds, indoors and out. Conditions for mosquitoes would seem to be ideal; but in every tub, every pond and every pool little fish have been placed, and in the course of a somewhat hasty inspection I found no trace of larvæ. I was assured that there were none, and learned immediately thereafter that the tank connected with the copying press, in the office, having been neglected for a week, had been found swarming with them.

Mr. Seal, besides carrying on the line of work already referred to, collected carefully, from all sorts of places, mosquito larvæ, which were sent me alive, and thus I obtained several forms of great interest; one of them never before bred.

Mr. J. Turner Brakeley, of Lahaway, was a voluntary assistant, to whom I owe a full line of specimens from the pines, accompanied by full records of careful observations. Some of these observations have been already used, some are referred to in the body of this report and some will form part of the life history of the species that I hope to present in a final report. Two species never before bred by any one were obtained at Mr. Brakeley's place in the pines, and other species not before bred by me were also received. Altogether, Mr. Brakeley's contributions toward a knowledge of the life history and habits of the New Jersey mosquitoes are of the highest value.

Mr. E. L. Dickerson, of Newark, New Jersey, was with me during the year, mainly as assistant in the work of the State Entomologist, but also engaged as an aid in the mosquito investigation. He made many interesting collections, and as an example of the possibilities of municipal work I had him make a survey of the city of New Brunswick, locating on a map all the places where he found mosquito breeding places, together with suggestions as to how each place should be dealt with.

Beginning June 20th, Mr. Otto Buchholz, of Elizabeth, New Jersey, began a series of collections, near his residence on Adams avenue, to determine the species of mosquitoes that occurred during the summer. Collections were made both indoors and out, at about five-day intervals, and on a subsequent page will be found a list of his captures, which is interesting and suggestive.

Personally, I have been in almost every part of the State, have consulted with improvement societies, or their representatives, have suggested lines of work for local bodies and have made inspections, where it was necessary, to arouse interest and give information. But my principal line of work has been in connection with the salt marsh or shore mosquito, which, whatever may be the case elsewhere, is likely to make local work within its range unsatisfactory and only partially effective. Its range this year has not been exactly the same as it was last year. In 1901 it was the dominant species at New Brunswick for weeks at a time, and my garden was so full of specimens that, when evening approached, it was an unpleasant place to remain in. In 1902 there was not a day when this species was troublesome; it was never the dominant species and very few specimens were in the garden.

A record of what I have learned about this species during the season is presented on a subsequent page of this report. One of the collateral results of my own work was the engagement of Mr. H. H. Brehme, of Newark, to make a survey of the Newark meadows, and during the six weeks many important facts were learned that will have a bearing upon the practical work of dealing with this species. At Elizabeth an organization had been formed to fight the local mosquitoes; but

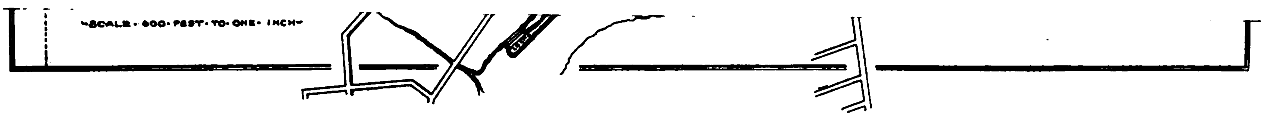

Fig. 1.

Map of the City of New Brunswick showing where mosquitoes breed. The red areas are the breeding places.

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Dr. Wm. F. Robinson, who was in charge, recognized so well the importance of the salt-marsh form in the problem, that he secured the appropriation of a sum sufficient to keep Mr. Brehme in the field two weeks longer than would have been otherwise possible.

The results of Mr. Brehme's work are also presented herewith.

Altogether, something over twenty species were bred, and, so far as collections go, there are only three species of mosquitoes taken in New Jersey whose larvæ are unknown to me.

A discussion of the results obtained from observations on other species than *Culex sollicitans* must go over until a future date and for a final report.

Observations on the Salt Marsh Mosquito.

The observations made on this species during the summer of 1901 left no doubt in my mind as to its importance in the general problem. With this insect removed, the seashore would be practically free from mosquitoes; and not the shore only—the pines for miles back would be freed, and the shore area would be increased in value by many millions of dollars. It seemed a stupendous task and beyond all reasonable hope of attainment; but the estimates were formed on beliefs rather than facts, and my task was to discover the facts.

First of all, the winter home of this marsh species was unknown, and while it was assumed that hibernation was in the adult stage, no one had actually found the species. So, on April 4th, I sent Mr. Dickerson to Anglesea, with instructions to hunt mosquitoes in all sorts of likely and unlikely places, but to find the adult if it existed. Anglesea was selected because I knew the place thoroughly, knew many of the people, knew that there had been many specimens during the summer of 1901, and knew that I could get access to cellars and outbuildings.

During the afternoon cellars were examined and storerooms under club-house, etc. The results were twenty-six *Anopheles maculipennis* and four *Culex pungens*. The bathing pavilion and the area underneath it yielded nothing. Next day a vacant house netted thirty-five *Anopheles maculipennis* and nothing else. On the bay side of the island wrigglers were found in salt pools at the edge of the meadow, under shelter of a high bank covered by trees and shrubs—a warm corner, sheltered from cold winds. The larvæ were in various stages of development, but some of them were very small, as though recently hatched.

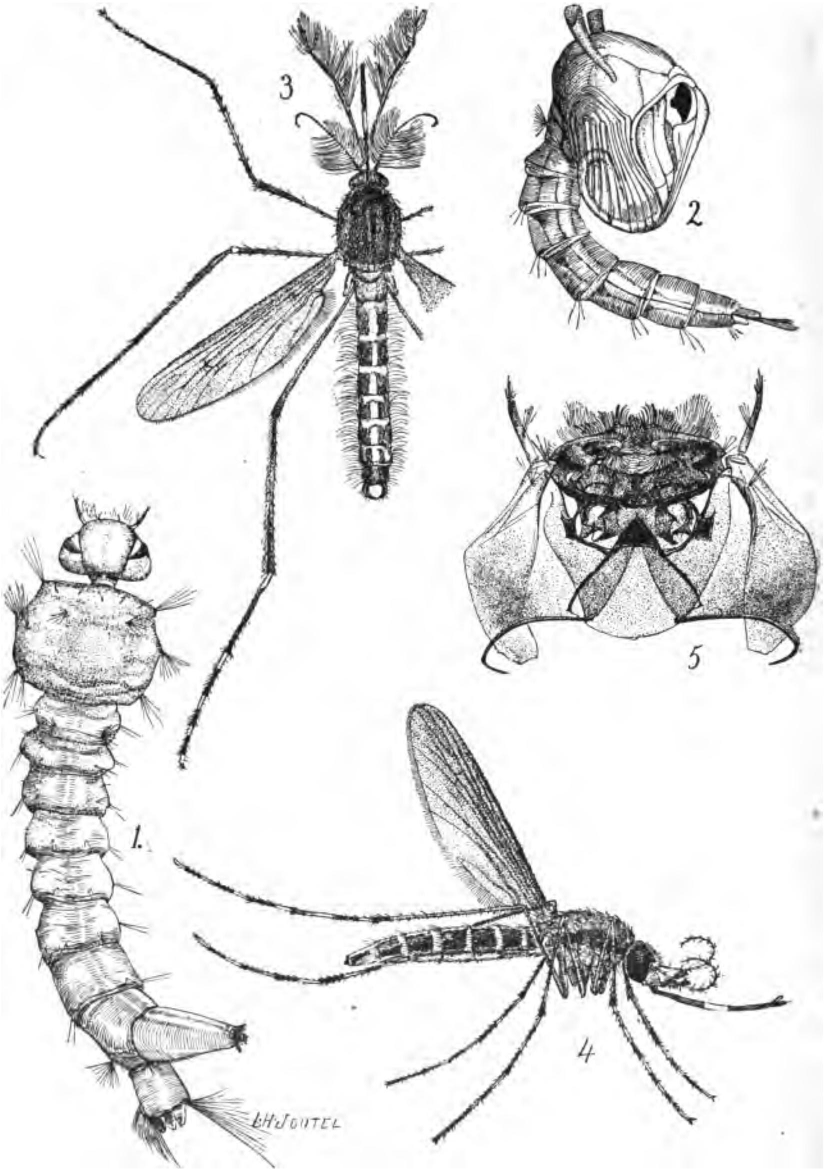


Fig. 2.

The Salt Marsh Mosquito, *Culex sollicitans*: 1, larva; 2, pupa; 3, adult male from above; 4, adult female from side showing the banded beak and legs; 5, head of larva; all greatly enlarged. From an original drawing by L. H. Joutel.

The results of the trip were not satisfactory, and on the 11th Mr. Dickerson again spent a day at Anglesea, this time hunting in the woods, in hollow trees, under bark, under overhanging banks, logs and natural shelter of every description. Attempts were made to start adults among the tall grass and from other conceivable places of concealment along and near the edge of the meadows. All without results, since not a specimen of *sollicitans* could be found. But a lot of larvæ was brought up, from which *cantans* and *sollicitans* hatched, in almost equal numbers, between April 14th and 21st.

The pools from which these larvæ were taken fill up only in very high or storm tides, and evaporate and fill up as it rains or shines, the water ever becoming less salty until another tide comes over it.

April 19th and 20th I spent at Anglesea myself, and not far from the hotel found a pool just beginning to dry up and already swarming with larvæ; another, not far off, was in the same condition, but here the larvæ were very minute—not over a day or two old. Searched closely for egg-boats or traces of them and for adults that might have been parents to the recent larvæ, but found nothing. Tramped over a large marsh area, finding no larvæ in ditches or salt ponds. In one area of very wet meadow, with little holes, two-thirds of an inch in diameter and as deep, I tried dipping out one of the holes, and, to my surprise, found larvæ. Every little hole over this entire area had a few wrigglers as inhabitants. One fact forced itself upon me: no deep pools, even if completely shut off from the tide, had any larvæ of any size. Not until the pools began to dry up did the larvæ make their appearance. Those that were nearest dry had the largest wrigglers; those that were but recently cut off and only a little dried out had the babies.

The apparent suggestion was that it was a matter of temperature, and that eggs would not hatch until a certain degree of warmth existed; but that, again, meant that the eggs were under water, ready to be hatched, and must have been there all winter. This was contrary to all the books, and could not be too hastily accepted; but, at all events, the matter of temperature could be approximately determined. The only thermometer available was a cheap affair, in the ordinary tin casing, and it may have been off to some extent; but the results have a comparative value at any rate. The temperature of the air at 9 A. M. was 48°; temperature of sea water, 50°; temperature of the salt pools from which the larvæ were taken was 52°;

temperature of the old salt pools where the larvæ were taken on the 11th and were now most advanced, 55°.

Fresh water temperatures taken during the morning in ditches and wood pools was 52.5° to 53.5°. In one case, in a rather large swamp area, it dropped to 50°. Not a larva was found in any fresh water body that morning. In the afternoon waded into a flooded meadow area in front of the railroad station and found larvæ everywhere; also one pupa. This meadow slopes naturally toward the seashore, and in cutting and filling the streets a large tract sloping to one corner was left without outlet.

It was entirely dry in the fall of 1901 and did not fill until winter was well advanced. Then it became all flooded, served as a skating rink during the winter and as a boating pond earlier in the spring. It was never tide-filled, and the water, when I tasted it, seemed entirely fresh. Drying up had begun, and over a large area there was not over an inch of water.

I made a very close search for adults near and under the bathing pavilion, but found none.

From the pupa brought home by me, *Culex sollicitans* emerged, and April 25th sent Mr. Dickerson down to make thorough collections from this body of water. He brought back a large lot of larvæ and pupæ, and from all of these *sollicitans* was bred. Mr. Dickerson reported the meadow as drying up fast and that, as the water receded, the larvæ became more crowded and seemed comparatively more numerous. All the salt-water pools were now filled with larvæ, and five bottles of wrigglers were brought back from as many different areas. *Sollicitans* only was bred from all the bottles, and it was certainly established that salt water was not essential to its development. Absolutely fresh water did just as well. Moreover, as this area was dry for some time after the mosquitoes had disappeared for the season, and none of the pests having been found before the larvæ made their appearance, it seemed almost certain that the eggs must have been there before the water covered the ground; in other words, the eggs are laid on dry sod land and hatch only when covered by water of a temperature some degrees above freezing.

Breeding being now fairly started, matters were left until well along in June, because of a press of other duties. June 14th, spent another day at Anglesea and, in company with Captain Hankins, investigated a portion of the salt meadow area lying between five-mile beach and the mainland. To my very great surprise, found that this area is really very well drained, very flat and swarming with fiddler crabs. Salt ponds in plenty; some deep, some shallow; but fish in all of them and not a mosquito larva. Captain Hankins tells me that much of the salt marsh area is exactly like this, and, during the four hours or more that we rowed through creeks and tramped over suspicious sections, not a wriggler was seen. Many miles of this meadow land will need absolutely no treatment whatever, and breeds no mosquitoes. From hour to hour the conviction grew that, were the broad meadow itself the only area to be treated, the matter would be very simple.

On returning to the hotel from the pier, noted a small duck pond filled with larvæ, and on both sides of the road tide pools, now drying up and absolutely swarming with larvæ and pupæ. Males had just begun to issue and they rose in clouds from the grass at the edge of the pools, but, of course, could not bite. No females seemed to have issued as yet. In this series of pools, the largest not over fifteen square feet in area, hundreds of thousands of larvæ were developing; more than were on the entire square miles of marsh area I had covered that day. A few quarts of kerosene would have killed the whole brood in a few hours; a few loads of sand from the adjoining sand hills would have permanently cured the whole matter. I called the attention of the mayor of the town and of the proprietor of the hotel, not over 100 yards way, to this condition of affairs. The former expressed great astonishment, the latter great disgust; neither of them did anything else, and that series of pools continued to develop mosquitoes throughout the summer.

On the evening of the 14th met with a number of persons interested, in Cape May, at the Marine Villa, by invitation of Mr. John M. Rogers, who has urged measures for mosquito destruction or control for years past. Mr. Frank M. Jones, of Wilmington, Delaware, was also present as the guest of Mr. Rogers, and informed me that he had made a preliminary survey of the territory, finding very little that could be considered dangerous, and a very few larvæ.

A very superficial examination of the surroundings was made on the 15th, and from what appeared, Cape May City can very easily rid herself of all local breeding places with little trouble and expense. There is a rather extensive swamp between Cape May City and Cape May Point, near the light-house; but it was very dry at that time and very difficult to say what this place would do in a wet season or when overflowed by a tide. The region toward Sewell's Point is said to be a great mosquito-breeding country, but I did not get to this place at all during the season, though I intended to do so.

June 20th, saw Mr. A. V. Dayton, then Superintendent of the West Jersey and Seashore railroad, at Ventnor, and looked over with him some of the ground between Ventnor and Longport, where mosquitoes become very numerous and from whence they sometimes get into Atlantic City. I was able to point out to Mr. Dayton how, sometimes, "improvements" created breeding places by leaving low areas without outlets through street or road fillings or railroad dams. One especially bad area had been made so by filling in a street which cut off the access of tide-water that had previously reached it. Mr. Dayton promised co-operation by the railroad company in the general aims of the work, and it was at his suggestion that Special Bulletin T was prepared. Nearly or quite 100 copies of this Bulletin were sent to division superintendents for distribution among those in charge of the right of way, with instructions to abolish mosquito breeding places, so far as possible, whenever such were found.

The line of work now being done at and near Atlantic City is fast doing away with mosquito-breeding places at the edge of the marsh, but some bad areas are left and others are created through ignorance of the conditions which favor the development of these insects. It is believed that a careful survey of this area, pointing out the conditions that favor the breeding and the dangerous area, will result in the rapid improvement of those conditions and the removal of the dangerous area.

Early in July, having decided, from the evidence obtainable, that *C. sollicitans* has altogether different egg-laying habits from those described for *C. pungens,* I planned a campaign at Anglesea that should result in answers to the following questions: 1. Where do these mosquitoes lay their eggs? 2. How long does it take them to get ready to lay? 3. How many may one individual place? 4. Is it necessary for the female to feed before she is able to oviposit?

A series of seven tubs was sent to Anglesea from New Brunswick; Mr. Dickerson went down July 7th and I followed later in the day. The tub experiments were assigned to Mr. Dickerson, while I conducted a series of marsh explorations.

Mr. Dickerson's record is essentially as follows, up to the time that I left him in charge: Placed the seven tubs in the backyard of the Keystone Rod and Gun Club house so that only a few inches projected above the surface. In one tub put a few inches of salt water only and in a second some sod from the salt marsh, covered by two or three inches of salt water. Mosquitoes were very abundant here, and the tubs were left uncovered, to see whether any mosquitoes would oviposit in them. As breeding pools were rare at this time, it was hoped that these tubs would be very attractive. In a third tub sod was placed, with just water enough to keep it moist, and in all the others the bottom was covered with sod, and salt water, to cover well, was added.

Several jars of larvæ were collected in the afternoon, and in the evening a few mosquitoes were collected and placed in a jar, with a little water and some grass, to see if eggs could be obtained in that way.

July 9th, placed a jar of larvæ in each of the covered tubs containing water-covered sod, that the adults, when they issued, might have opportunity for oviposition if they so desired. In the afternoon experimented with Chloro-naptholeum on *sollicitans* larvæ. Four quart jars were more than half filled with decidedly brackish water and all were well stocked with larvæ. With a medicine dropper put in two, four, six and eight drops, respectively. An hour later nearly everything was dead in the jars containing six and eight drops; in the jar with four drops many were dead, and in that with two drops a few were gone. In this diluted sea water the Chloro-naptholeum forms a film on the surface, which drives the larvæ down when they attempt to pierce it. A few young fish and water boatmen in one of the jars were also affected. Yet an hour later everything was dead in all jars, except for one or two larvæ and some other creatures in the jar containing two drops. In the evening mosquitoes were collected in a jar and placed in the tub containing only moistened sod, that they might oviposit on it if they would.

July 10th, secured additional material for experiment, located several new breeding pools and sprayed two pools with Phinotas oil, very liberally applied. Two jars with pupæ were prepared, to test the comparative value of Chloro-naptholeum and Phinotas oil, and five drops of each were used. The Phinotas oil also produced a surface film, but did not make the water milky. Next morning the pupæ in both the jars seemed very little affected, and that was the case in the sprayed pools, from which adults were now coming in great numbers. Next day the pools had dried completely and the breeding pools were everywhere disappearing, layers of dead larvæ and pupæ being left on the surface mud in many cases. One matter was very definitely proved at this time—neither larvæ nor pupæ bury themselves in the mud as the water evaporates. When the water disappears they simply die, no matter what stage they may be in. To determine whether eggs had been laid in the water some of the surface mud from the recently-dry pools was obtained, part of it placed in jars and covered with water, and part was taken to New Brunswick and washed out in the laboratory; no eggs being found nor larvæ secured in either case.

On the 12th I left Mr. Dickerson in charge, and he carried on the experiment by keeping up the mosquito supply in the tubs, placing food in some and leaving others bare and whatever else was necessary.

Mosquitoes were also captured and confined in jars, with soil, with water, with tufts of grass and without any addition whatever. In almost all cases eggs were obtained without any trouble, and appeared on the leaves, on the ground, on the grass blades below the surface of the water and even on the bare glass. The insects were simply ready to lay and placed the eggs anywhere; usually they were black, but white ones also were laid in some places.

These eggs were left in the jars, some covered with fresh and some with salt water, some jars kept indoors and some outdoors under natural conditions; but in no case did they hatch while under observation—a period of four or five days.

July 15th, Mr. Dickerson sent me up some eggs obtained in this way, and also a few adults, of which five were dissected, with the following results:

No. 1.	Black eggs	46	......
	Gray eggs	17	......
	White eggs	101	164
No. 2.	White eggs only,	......	117
No. 3.	Black and gray eggs only	......	148
No. 4.	White eggs only	......	135
No. 5.	Black and gray eggs	47	......
	White eggs	35	82

As to No. 5, it was quite possible that it had already deposited part of its eggs. It is noteworthy, in view of what appeared later in the season, that at this time there was no difficulty in getting any desired number of gravid females.

July 16th, all breeding pools were practically gone; in the grass was a lot of old adults and a vast swarm of recently-developed forms, male and female; on the evening, with a west wind, the hotel porch and the beach to the water's edge became overrun with them. As the same wind continued next day, matters became much worse, until the whole shore area became filled with specimens.

July 18th, I reached Anglesea again myself, and on the 19th all the tubs were overhauled and Mr. Dickerson's observations collated.

The uncovered tub, No. 1, was kept with from one to three inches of sea water during the two weeks that it remained in the ground. No larvæ developed at any time and the water remained clean. It was always cooler than the water in the surrounding pools, but was always warm enough for mosquito development. On the 19th found a little group of ten or twelve eggs at one side of the tub, near the surface of the water, and they seemed to be of this species. Nothing was in the water itself. In view of the fact that mosquitoes were very abundant in this place and that they had had two weeks in which to oviposit, it would seem to be a fair conclusion that eggs are not laid in permanent, open bodies of water. This is borne out by the fact that I have never found larvæ in pools with clean edges and without vegetation. There are many such ponds and pools on the salt meadows and they may in general be accounted safe. So, on sand flats and mud flats, I have frequently seen large areas of shallow water, in which no trace of larvæ was found. The eggs found in this tub were placed in a cup of water, but were afterward mingled with others obtained under natural conditions, so I cannot tell whether these hatched. The eggs sent to me at New Brunswick had tended to split and break after three or four days, as if the contents had fermented and burst their envelope.

The second exposed tub was bottomed by mud-covered sod, flowed by an inch or more of salt water, and this was intended to represent a grassy pool. The water evaporated pretty close to the surface at times, but it was never allowed to go quite dry. No eggs were noted in this tub at any time, and when the whole matter was dumped out and examined on the 19th, neither larvæ nor eggs were to be seen. No natural breeding pools were near by at the time, and if that sort of locality is favored, this would have been an ideal place. Nevertheless, after two weeks, not a wriggler was found in the water, every particle of which was closely examined and not an egg was found on the grass, almost every blade of which was examined with a lens. It would seem to follow from this, added to observations made at the edge of the marshes, that the insects will not oviposit in any water-covered areas.

Tub No. 3 was covered with mosquito netting and had a bottom layer of sod, which was kept moist. A jar of mosquitoes was collected July 8th and turned loose under the netting. It was noted at the time that all were females and that many of them had the abdomen fully distended as if by ova. Adults with fully-developed ova were collected a day or two later from the same area, hence this point may be considered as beyond reasonable doubt. July 14th, the mosquitoes were dead, and salt water was added until the sod was covered. This tub was intended to imitate a moist marsh area, in which mosquitoes had an opportunity to oviposit, and when the water was added the eggs, if any were laid, should have an opportunity to develop. On the 19th no larvæ were found in the water and no eggs were found on the sod. I cannot quite explain this failure to find eggs at any rate, unless they went to pieces, like those in the jars. In view of what was later found, the indications would seem to be that the eggs need a certain period of drouth, during which development takes place, and that if they are water covered too soon after they are laid, they burst.

Tubs 4, 5, 6 and 7 were all covered with mosquito netting, all had sod bottoms and all had water enough to cover the surface. Live mosquitoes were placed in each tub, and also a jar with numerous full-grown larvæ and pupæ. No definite information was gained from these tubs, all of which were bare of either eggs or larvæ when examined.

All the indications pointed now to eggs laid dry in mud or sod and, first of all, samples were secured from the bottom of a pool that dried out a week previously, after having matured a large lot of mosquitoes. The soil was sandy, with a crust of organic matter about one-sixteenth inch thick, which tended to become dry and leathery. No eggs were found in this. From another pool other samples were washed, and dead larvæ and pupæ were floated out, but no eggs. Then sent Mr. Dickerson to cut out a section of sod from an area where we had found mosquitoes abundant on the 8th and 9th. This was near a pool that dried up completely on the 11th, but the area from which the sod came was already well above the water line on the 8th, and had certainly been dry at least several days before. The section brought in was about four inches square, was moist, the surface mud covered, and, when I examined the edges with a lens, I at once found the eggs imbedded in it. The mud was about one-fourth inch thick, the grass was very dense, and below the mud was a tangled mass of root fibres, like green turf. A small portion of this surface was washed out and eggs were found in it in such numbers that there could be no doubt that this was their natural home. When they were deposited there, could not be even approximately determined. Gravid females were there on the 8th, but they might have been there long before, and what eggs were obtained from those taken on the 9th failed to develop larvæ.

Having determined the presence of the eggs in some number, I cut the grass close to the surface and washed the mud into a granite basin until the tops of the grass roots were washed clean. The basin, half filled with fresh water, was left until the mud settled a little, to make sure the eggs did not float, and was then placed on a table in the club-house at 9 P. M.

I should have said previously that, by the courtesy of the members of the Keystone Rod and Gun Club, of Philadelphia, these experiments and investigations were carried on at their club-house and in the grounds surrounding them. I take this opportunity to acknowledge the courtesy and to express my gratitude and appreciation for the assistance rendered.

Next morning, at 8 A. M., the granite basin was swarming with wrigglers. We made no serious effort to count them, but there were 300 certainly, and perhaps 500.

Two sods were cut on the 21st, from the same general area where the eggs had been found, and these were carried to the laboratory, where one was placed in a large dish containing an inch or so of water, that it might be always thoroughly moist or even wet, yet the water was never allowed to come so near to the mud surface that eggs could fall into it or larvæ hatched in the wet mud would be likely to reach it. The other was placed in a large, porcelain, evaporating dish, so that air could circulate all around it, and no water was added so long as it remained there. The fortunes of these sods will be followed on a later page.

On the 18th and 19th collected a large lot of mosquitoes for examination, at the hotel porch and in the grass around the old pools, and did not appreciate, until later, that I had in view the end of one brood and the beginning of another that was destined to represent the species at Anglesea for several weeks before there could be local additions to it. Gravid females were already present on the 8th, and on the 18th they occurred in the same places—worn and battered examples, low down in the grass, caught only by sweeping closely in the early evening.

On the 8th, also, we found a new brood coming out from the fast-diminishing pools, and thousands of males were seen. On the 19th no more males were found; but the fresh females swarmed in the grass and came to the hotel porches in great numbers. Not one of these females contained even a trace of ovarian development. The males were gone; it is fair to assume that they fulfilled their purpose in life before disappearing; but it is equally certain that of all the flying swarms that were ready to attack none was in position to oviposit. There was not even a trace of an enlargement of the ova in the ovarian tubes.

Of the material collected in the grass over 100 specimens were examined and the developing ova were counted. In stages of development they ranged from half to full-grown eggs; the latter from soft white to gray, translucent. In number of ova the range was from 75 to 200, with an average of about 175. It was a notable fact that in the great majority of cases obvious remnants of blood food were found in the alimentary canal, where the ovaries were well developed. So general was this that the exceptions were considered as cases where the material had been so completely absorbed or excreted as to make its recognition impossible to ordinary examination.

While Mr. Dickerson was arranging for the details of the tub experiments, I explored some of the marsh areas, with Mr. Richard Button as boatman and guide. On the 8th rowed through Beach creek to Wildwood and then across to the marshes basing the upland. Landed at several points and from the boat examined the flat lands. Tramped about a mile of marsh to the upland, diverging wherever pools could be seen. Everywhere there were fishes, large and small, fiddler crabs and other creatures, but nowhere any mosquito larvæ. Nor were any encountered until the land began to rise and we were beyond the range of the ordinary monthly high tides. When we reached that point some mosquitoes began to rise in the grass in front of us, and in a little while I began to find larvæ in the holes filled with water, where there were no fish nor crabs. As soon as we struck the real upland everything was full of mosquitoes, and I found that every little hole, every pool and every little run that came into the marsh had its wriggler fauna. The rise here is rather sudden, and the line between mosquitoes and no mosquitoes is sharply marked. The number of breeding places in this area is rather small, and there would be little difficulty in draining this so as to get rid of all these pools at the edge of the upland. The interesting and important result of this trip is a confirmation of the conclusions reached in June—that the salt marsh area, as a whole, is not to be considered dangerous as a mosquito breeder. No salt pools free from vegetation contained any mosquito larvæ. Nowhere on the marsh, within the range of the tide, did mosquitoes occur in the grass in any number, and nowhere in any of the channels running through the marsh was there any trouble with them.

July 9th, we rowed over to Seven Mile Beach and landed on the bay-side, a little below the life-saving station. Crossed the marsh to the high, middle ridge and to the shore, noting nothing that was new. A very large pool had been left by a high tide in a sandy basin, and this was slowly evaporating; but it contained no wrigglers. This was expected, for the insects do not oviposit on bare sand.

At the life-saving station, Captain Ludlam, who was in charge, said that mosquitoes were never very numerous to the south, but came from the west and went northwardly, while the woods toward the bay-side were always full of them. Crossed this woodland, which more than justified what had been said, and beyond it found a circular, depressed area or basin 200 feet or more in diameter, with from one to three inches of water, in which grass was growing everywhere. The water was lukewarm and was actually alive with wrigglers and their pupæ. Adults, too, were swarming, and, altogether, a more ideal mosquito breeder it would be impossible to imagine. The water was salt as the sea itself, and was undoubtedly tide-water, with very little addition from springs in the woods above, which did not furnish enough to prevent its gradual drying up. The place is completely cut off from ordinary tides; sand hills, ten to fifteen feet high, surround it almost completely, and to the east they are tree-covered. Toward the west, or bay-side, is an opening in the hills, forming a bar about one foot above the general level of the basin. Over this bar the tide gets in when the whole marsh is flooded, and on such occasions very few fish seem to be carried up so high. Literally, millions of mosquitoes had hatched and would hatch from this area, and, with a southwest wind, would fill Piermont, Stone Harbor and Seven Mile Beach in general; with an easterly or southeasterly wind they would drift to Cape May Court House and other places on the peninsula. This is one of the places from which come the great clouds of specimens that fill the pines and the South Jersey region in general. A ditch through the dam closing this basin, draining it to the general salt marsh level, would cure this place at once;

and such places as this must be sought out and cured to free South Jersey from the mosquito pest.

July 10th, rowed to Shell Beach Landing, toward Cape May Court House. Explored the marsh to the upland, and found this to be the best natural gradation into upland that I had seen. The marsh is very level, and where it begins to rise above ordinary high tides, salt hay may be and is grown. From the edge of the marsh to the base of the upland few mosquitoes were found, and no larvæ were in the pools, which mostly contained fish. Along the upland some mosquitoes were encountered, and, in a deep ditch made to get material for a road, found plenty of wrigglers. Had some conversation with one of the oystermen, who tells me that the monthly high tides cover the marsh completely to the upland, except in August and early September. The last tide had occurred on the 7th or 8th of July, and this would not be equaled again until late September or October. All the pools left by this last tide contain minnows, but these would die in about a week, when the pools dried up, and then, when it rained and filled the pools once more, they would be full of wrigglers and would swarm with adults. This is practically what Mr. Seal has claimed for certain species at Delair, and it is in accord with the observations made by myself.

The three days on the marshes of this area proves very conclusively—*first,* that by far the greatest area of salt marsh land between the edge of the mainland and the edge of the islands lying parallel to the coast is not and cannot, under ordinary conditions, become dangerous from the mosquito standpoint; *second,* that wherever the little species of minnow (*Fundulus*) can maintain themselves from tide to tide no mosquitoes can or do breed; *third,* that the breeding places are at or near the edges of the upland, where pools are left which the low, summer tides do not reach; *fourth,* that the first breeding places of spring are those areas very high up, covered only by the highest winter tides, which warm up early and bring to maturity a brood from the eggs that had wintered over.

It has been recorded that on July 21st two sods were gathered on the meadows at Anglesea and brought to New Brunswick.

July 31st, cut off about two square inches of the sod that had been kept dry, washed the top layer of soil into a glass dish by means of a pipette and left it over night. August 1st, Mr. Dickerson counted 117 young larvæ. Growth was slow, perhaps because of lack of food and fresh water, and on the 11th put in a bit of salt sod, about which all the surviving larvæ at once grouped themselves. August 12th, first pupa; August 13th, three more pupæ; August 15th, several more pupæ and one male adult—*Culex tæniorhynchus.* About a dozen adults were bred from this lot and every one was *tæniorhynchus.* In view of the fact that nothing but *sollicitans* adults occurred where these eggs were taken, this was rather startling!

August 10th, cut off about one square inch of dry sod, rubbed it up in fresh water in a glass dish, and left it there just covered. At 10 A. M. a dozen or more wrigglers were already hatched and moving about in a most lively fashion. As I was desirous only of testing the vitality of the egg, I did not carry further, but placed the larvæ in alcohol.

August 10th, cut off about two square inches of the wet sod and placed it in a dish, just covered with fresh water. At 9 A. M., fifteen minutes later, saw two eggs floating on the surface. Next morning no larvæ had developed, so the sod was cleaned out, and in the mud Mr. Dickerson found a few eggs and many egg fragments. It is obvious that the eggs were there sure enough, but that something hindered their hatching.

August 11th, cut off two square inches of wet sod and washed off the surface into a glass dish at 7:30 A. M. Four eggs floated to the surface during this operation. Next day there were more floating eggs, but no traces of larvæ.

August 12th, 8:45 A. M., Mr. Dickerson washed off a small piece of dry sod and began collecting the eggs for preservation. At 9:15 A. M., just half an hour later, he reported that larvæ were beginning to issue, and I had an opportunity to see the pure-white wriggler just out of its shell. About one-fifth of the egg lifts off and folds back, as if on a hinge, giving the little larva a chance to work out.

Placed the piece of sod that had been washed into a large dish, and in another hour had more little larvæ, which, again, were not bred.

August 25th, placed a piece of dry sod in salt water from the Newark meadows at 10:15 A. M., and at 12 M. larvæ began to hatch. Quite a fair lot of them was obtained, and pupation began September 4th. The first adults issued on the 6th, and on the 9th, when the culture was closed, I had a dozen adults—all *tæniorhynchus*—and as many larvæ and pupæ.

Other small pieces were taken from the dry sod, from time to time, and some were given away; in every instance larvæ were obtained in a short time, but none were bred to maturity.

From the wet sod similar fragments were taken, and in all cases the results were negative—*i. e.,* no larvæ hatched, though in every instance floating eggs were seen.

September 21st, placed the entire remnants of the wet sod in a large dish and covered with water. Next morning, to my surprise, a number of larvæ was observed, and on the 25th fifteen examples were transferred to a small dish containing clean water and a piece of fresh sod. This transfer became necessary, because the old sod was getting very foul and the larvæ were dying off. On the 29th the first pupa formed, and October 1st there were six more pupæ and three larvæ. October 2d, there emerged one male *tæniorhynchus,* one male *sollicitans;* October 3d, two female *tæniorhynchus;* October 4th, one male and one female *tæniorhynchus* and one female *sollicitans;* October 5th, one female *sollicitans.* In all, eight specimens, of which five were *tæniorhynchus* and three were *sollicitans.* If we have two species, their eggs were mingled in the same sod, and the larvæ were so nearly alike that no differences were noticed. The surprising thing was that any egg should survive so long a period on a soaking wet sod!

October 4th, placed the balance of the dry sod in water, to which a little sea salt had been added. This was done at 10:50 A. M., and the sod was so dry that it was necessary to weight it down to get it covered by the water. At 1:30 P. M. little wrigglers were in the water, all around the edges of the turf, and next day over 100 specimens were actually counted.

On the 8th, as the water was becoming foul from the old sod, transferred about 150 larvæ to clean water, to which sea salt and a piece of broken-up sod had been added. There was at this time a great difference in the size of the larvæ, indicating a very unequal rate of development.

About this time there was a cold spell, and as there was no heat in the laboratory during the night, growth was very slow and the water tended to become foul. Finally, on the 24th, sixteen days after they were hatched, the larvæ were yet scarcely half-grown, many had died and the remnants were bottled; and thus closed a very interesting experiment, by which it was, for the first time, definitely proved that species of the genus *Culex* lay their eggs singly, in dry or most soil, and that for months they may lie thus, ready to hatch when covered by water of a proper temperature.

Incidentally, the same points are proved for *Culex tæniorhynchus,* assuming that it is really a distinct species.

July 21st, I spent a few hours at Avalon, with Mayor Gilbert S. Smith. The conditions there are not essentially different from those existing at Five Mile Beach, save that there is more opportunity for breeding at the base of the upland; but, on the other hand, tide ditches come to this point, so that drainage into the level meadow will not prove a serious task. All the specimens collected here were such as came to bite, and of these not one had any appearance of developing ova—all were fresh, clean specimens.

August 4th and 5th, was at Beach Haven and examined rather carefully the conditions existing in that immediate vicinity. Did not get north of Barnegat Junction; but south of that point to Beach Haven, and for some distance south from that, breeding places can be completely abolished at very little trouble and expense. The island is very narrow and the marsh area on the bay-side is low, so that even shallow ditches would carry tide-water to the edge of the upland. There is a little series of hollows, made by street and road fillings, which can be very easily filled or drained. It had rained heavily just before I got there, and young larvæ were in all the recently-covered areas. It rained very heavily during one night of my stay, and the next day, wherever there was an inch of water in the meadows, it was swarming with little wrigglers. In the early afternoon much of the area had dried up completely, and the wrigglers were dead, of course—more millions having perished in this way than survived. Where the water had been deeper the larvæ were now much more crowded, as evaporation at the edges drove them to the centre. Had there been a week of wet weather this entire brood would have reached the adult stage.

One lot of twenty-eight mosquitoes was captured in the evening as they came to bite, and one of them succeeded in getting a full stomach before I bottled it. None of the specimens had the ovaries in the least developed.

Another lot of twenty-three specimens was captured at the edge of the marsh land, and of these ten had had a full meal of blood. All save one had undeveloped ovaries, and in that one the eggs were half-grown or more and remains of blood food were evident in the alimentary canal.

The observations made here supplement those made during 1901 at Seaside Park, and show that eggs are everywhere on the lower meadows, and that, wherever the mosquitoes may be in swarms, there they will oviposit. Millions of eggs never hatch at all; other millions hatch, as did those above mentioned, when rain comes, and perish within a day or two when the water dries off.

August 15th, I was at Lahaway and found everything swarming with *sollicitans.* During two or three days of collecting, Mr. Brakeley and myself found the larvæ of five species of mosquitoes, the adults of which were so scarce as to be hardly noticeable; but not a larva of *sollicitans* was found. A few days before my arrival Mr. Brakeley had collected ninety specimens which came to bite while he stood quietly a few minutes, and these I examined later. Only two of them had succeeded in getting blood, and none of them had developed ova.

I captured 253 examples by sweeping in the grass to make sure of getting gravid females if such there were; but though eighteen examples had feasted upon blood, not one showed any ovarian enlargement. Nor did I capture or see a male during my stay.

August 28th, went to Tuckerton from Philadelphia, and at Whitings *sollicitans* began to come into the train. Before we reached Manahawken it was a nuisance, and thence, to Tuckerton, from half a dozen to a dozen specimens were around almost every passenger. Drove to the edge of the marsh, about six miles from town, and mosquitoes were abundant everywhere. While my driver was explaining to me how sensitive he was to mosquito bites and how much he suffered from them, a specimen alit at the edge of his lower lip, gorged itself with blood and flew away, the speaker remaining completely unconscious of the curious contradiction between his statement and the actual fact. Clouds of mosquitoes arose at the edge of the marsh, and other clouds arose at every step on the way to the De Mott oyster-house, where Dr. Nelson was carrying on his oyster work. About an hour was spent here in collecting, and it was notable that not a male was seen; furthermore, the females had a rubbed and faded appearance, as if they had lived a long time. There had been no rain for some time, and, according to Dr. Nelson, the marsh was drier than it had been at any time during the summer. Only tide-water was found, except a few pools swarming with fish. Twenty-four hours more without rain would dry these pools and kill the fish, leaving excellent breeding places after the next rain. This is a very low, soft marsh, not much above ordinary high tide, with many depressions and holes in which water will stand. Wagon roads lead across it in several directions for carting salt hay, and in these roads wrigglers swarmed earlier when the marsh was wet. Dr. Nelson says that he has crossed this marsh when every hole was full of water and every pool of water was a mass of wrigglers. In the afternoon skirted the marsh in a gasoline launch with Dr. Nelson and Dr. Lightfoot, to the Mullica river, and afterwards up the Bass river, to the New Gretna landing. The whole marsh was swarming with mosquitoes and was of the same general character as already described; but everywhere the absence of males was noted. From the landing to the hotel at New Gretna was a walk of one and one-half miles through clouds of mosquitoes, and outdoors in the evening was unpleasant to say the least. Yet indoors mosquitoes were few and in the bedrooms none at all, though no especial precautions were taken. Drove from New Gretna to Pleasantville, a distance of sixteen miles, much of it along the edge of the marsh, through mosquitoes everywhere. This area at the mouth of the Mullica river is by all odds the most extensive breeding place I have found, and forms one of the main centers for the distribution of the insects to inland points. The few hours I spent here served only to bring out that fact and pointed to this as a place that must be thoroughly investigated when time and money are available.

One hundred and twenty-four specimens were collected on the marsh, and of these, 117 had neither food remnants nor developing ovaries; two had remnants of blood food, though no ova were obvious; one example had fed upon blood and the ovaries were developing, but the eggs could not yet be counted. In four specimens, in which no food remnants were apparent, the ovaries contained 17, 33, 105 and 113 full-sized eggs, respectively. Except in the last, the eggs were becoming grayish, translucent. I could not determine whether the females containing the small number of eggs had really developed no more or whether some had been previously laid.

Two bits of sod cut out of likely places in the meadow were placed in salt water before I left Dr. Nelson's quarters, but according to his report no larvæ had developed from them more than twenty-four hours afterward.

September 2d I spent at Newburyport, Massachusetts, and on the marshes along that coast, examining a ditching machine; this point will be again referred to, elsewhere.

September 3d, forty-two examples of *sollicitans* were collected for me at Anglesea, and none of these, when examined, showed either food remnants or growing ovaries.

September 11th, Mr. Dickerson went to Anglesea again, and on the 12th collected a series of twenty small sods from half as many different places and tested small bits of them in tumblers before bringing them to New Brunswick. Positive results were obtained with eight sods only. There had been heavy rains a few days before, all the lower surface depressions were full of water and all were swarming with small larvæ. Hence, there had been a general recent egg-hatching in the best places.

It may be added here that, from the area where the sods turning out *tæniorhynchus* were obtained, nothing but *sollicitans* had ever been taken from the pools.

The sods were started September 14th, in small battery jars, and larvæ developed in six of them; but the water turned foul very rapidly and I lost every specimen before it became anywhere nearly full-grown.

Of the adults brought up by Mr. Dickerson, thirty-six specimens were examined, and of these twenty-three had undeveloped ovaries and empty crops; nine others had been fully fed, but were otherwise not different; one had a goodly remnant of blood food and half-grown eggs; while three others, though showing no blood remnants, had the ova nearly full-grown and very numerous.

At this time Mr. Brehme's collections were under way, and these are elsewhere reported upon.

October 19th, Mr. Brehme sent me two sods from the Newark meadows; one was taken from the area near Hamburg Place, where so many larvæ had been found; the other came from the Bound Creek district, where, also, larvæ had been numerous and where the meadow had since been burned over.

October 28th, a piece, four inches square, was cut from each of the sods at 11 A. M. and placed in a glass dish, with fresh water. No larvæ developed in either during the day, and next morning both were placed on a radiator, to try the influence of warmth. No better results were obtained in this way, and the effort was abandoned.

November 5th, what remained of each sod was carefully washed, so as to bring all the surface mud into glass dishes, and this material was carefully examined by Mr. Dickerson. Not an egg or an egg fragment was found in either dish.

October 23d, between 4 and 6 P. M., Mr. Dickerson collected 13 males and 119 females at the foot of Hamburg Place, Newark. A slight wind was blowing and the insects did not rise readily until dusk, when he saw them float with the wind for several yards before attempting to alight. In three only of the females had the eggs begun to enlarge.

October 30th, another collection was made at the same place and sixteen *nigritulus* and forty-six *sollicitans* were obtained. None of the latter had developed eggs and only one had traces of blood food.

Points to be Investigated.

It will appear, from the previous record, that much has been learned concerning this salt marsh mosquito, and much yet remains to be learned. The inability to continue marsh investigations late in fall leaves it a little uncertain under just what conditions the eggs winter. Nor do we know what temperature will bring them out in spring. We know that eggs may lie dry and maintain their vitality for months, hatching within a few hours after they become water-covered; we do not know how long they must lie dry before they can develop if water-covered. We do not know how many broods of the species there are or, under favorable circumstances, can occur. The only period when gravid females were at all abundant was in early July; after that time not a female was found that had black eggs within the body. We do not know how many times an individual may bite, nor whether blood food of any kind is in any way essential to the development of the ovaries. We know that the adults live for weeks; but how long they must live before they can reproduce is yet in doubt. Nor do we know certainly whether all the eggs are laid at one time or whether oviposition extends over any considerable period of time. Of hundreds of females examined in the pines and from points remote from the shore not one had developing ovaries or fully-formed ova. It is scarcely probable that these examples are infertilized, because males are always present in abundance before any females issue. But why do they not lay eggs? The insects occur by the millions throughout the South Jersey swamps and woods; but though there is water in abundance, not a larva has ever been found. Yet the species can and does develop in entirely fresh water along the shore.

The economic bearing of some of these points may not be obvious at first sight; yet, if there is a weak point in the insect's life cycle of which we can take advantage, it will come in connection with the early broods, and the start they get in the spring, and we must know all about that.

Newark Marsh Investigations.

Toward the end of the season, when I felt quite certain as to th general habits of the salt marsh mosquito, I secured the services o Mr. H. H. Brehme, of Newark, a well-known collector of insects an for years a member of the Newark Entomological Society. Hi assignment was to explore the salt meadow area lying immediately t the east of the cities of Newark and Elizabeth, to determine how much of this land was actually dangerous as breeding ground for the *Culex sollicitans.* From August 19th to October 4th Mr. Brehme was almost daily in the field, and during that time explored most thoroughly the area between the south bank of the Passaic river and the north bank of the Rahway river, and from the Passaic river, Newark bay and Arthur Kill on the east to the highland on the west.

An area of almost twenty square miles of the most difficult territory was closely surveyed in this way, and the breeding places were fully mapped out on separate-sheet maps supplied by the State Geological Survey. A reduced copy of the completed map is reproduced here, to show graphically and at a glance how really small is the actual percentage of dangerous marsh. A closer study will show that many of these bad places lie along the edges of the highland or near to some of the small creeks that cross this marsh, forming natural channels, into which the wet marsh can be drained by cheap ditches.

To ascertain what mosquitoes were flying on the meadows and what species bred there, Mr. Brehme collected adults as well as larvæ, in alcohol, sending in over 200 vials containing many thousands of specimens. All of these were carefully examined by me in the laboratory to verify the species and to ascertain the conditions under which the insects would breed. Quart jars of live wrigglers were sent in two or three times a week from the surveyed areas, and hundreds of adults were bred in the laboratory. It is safe to say that every species that can breed under the marsh conditions was represented.

A few words as to these marsh conditions. Almost the entire area is subject to overflow at storm tides and every part of the marsh is salt. There are a few islands of highland noted on the map, and the actual eastern bank is rarely submerged. All the creeks are tidal and the water is always at least brackish. At the edge of the highland, springs and brooks of fresh water come into the marsh and freshen the creeks at low tide. After a period of low, summer tides

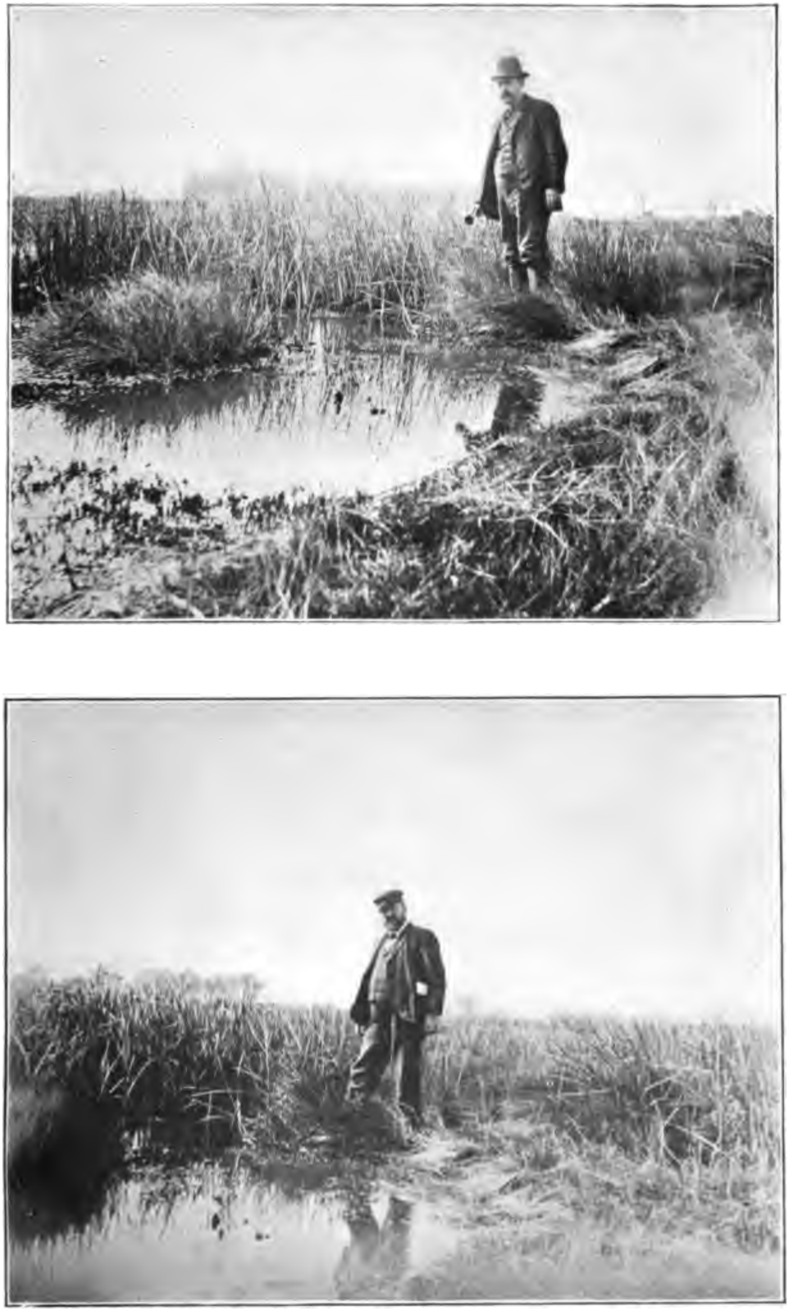


Fig. 3.

Typical breeding pools on the Newark meadows. The upper figure shows Mr. Brehme in collecting attire. From original photographs.

the water and pools near the highlands is practically fresh. An east wind, with a high tide, may in twelve hours change the whole into salt or brackish water. There are large stretches of the meadow overgrown by cat-tails, six feet or more in height, so densely as to make it impossible to get through, and these generally stand in from one to six inches of water; but no mosquito larvæ have been found in such places by Mr. Johnson, Mr. Brehme, Mr. Dickerson or myself, and each of us have sought diligently and at various seasons.

High, level areas that drain completely after every tide that covers them are safe, of course; and so are those low areas that are covered at every tide, even if by only two or three inches of water. Too many natural enemies exist here to enable mosquito larvæ to exist.

But there are areas of what may be called rotten meadow—just above ordinary high water—full of holes and shallow depressions, where walking is unsafe, and where, except on grass tufts, the boot sinks from four to six inches, leaving a hole that fills at once with water. Extra tides flood these places in spring and leave considerable water areas; some with and some without minnows or "killies" (*Fundulus* Sp.). Wherever the fish occur no mosquito larvæ develop; where none are brought in the pool soon swarms with larvæ, and later adults come in great numbers. Usually a droughty spell comes in early summer, that dries up many of the more shallow pools containing fish, and, of course, kills them as well as any other aquatic animals living there. A heavy rain may fill these pools before another high tide comes in, and there now being no fish, the water soon swarms with wrigglers.

Characteristic mosquito areas and pools are shown at Figure 3, both from the Newark meadows.

Mr. Brehme's Report.

Mr. Brehme's report to me was made partly by letter, partly in a written statement and partly in conferences had with him. To keep the whole in consecutive form and to include the names of the insects taken and observed, his statements and suggestions are here connected and combined. The map (Figure 4) should be consulted in connection with this report.

August 19th, the Great Island area was visited under the impression that it was probably one of the pest-holes in the marsh, but the entire day's work yielded not even one mosquito larva, though adults were present in large numbers. During that day, 169 small holes, 7 larger ponds and 11 ditches were examined, and, while a few small Hemipterous insects and some aquatic larvæ of Coleoptera and Neuroptera were found, not a wriggler was seen. The meadows here are low, are covered by even ordinary tides, and all the water bodies swarmed with "killies."

Only a few adults were taken, and of these two were *Culex cantans* and eight were *C. sollicitans.* Of the latter, four had not fed at all and the others had fed on something other than blood; in none of them were any ovaries developing.

August 20th, looked over a large area lying between Bound creek, the Pennsylvania railroad and Woodruff creek. There were not so many water bodies here and some places not within reach of the ordinary tides had dried up; others were very low, but everywhere there were "killies." Not a larva was seen or taken in this day's work.

Fourteen adults were sent in; of these only one had fed on blood, and in that one only were the ovaries developing.

August 21st, began at Great island and worked south to Elizabethport. Nothing was found north of Woodruff creek, though there were many pools to be examined. On the south side of Woodruff creek began to find pools containing larvæ, out of reach of tide-water. The samples of larvæ sent in proved, on study, to be *Culex nigritulus,* which, up to that time, had not been known to occur in this country.

Eleven adult *sollicitans* were sent in, and of these nine had the alimentary canal empty and the ovaries entirely undeveloped. One example had the abdomen distended by a blood clot; the ovaries undeveloped. The remaining example had nothing in the alimentary canal, but I counted forty-nine half-grown eggs in the ovaries. It should be understood that when adults are mentioned, females are understood unless otherwise stated.

August 22d, went over the region between Oyster creek, Newark bay and Woodruff creek, east of the Central railroad. No larvæ were found until Woodruff creek was reached, and then, in pools on both sides of that creek, they were plentiful. This breeding area can be very easily drained into Woodruff creek by short ditches. There are some ditches here, but they are partly filled and really make good breeding places for the mosquitoes.

Of the larvæ sent in, one vial contained a number of less than half-grown *sollicitans* and all the others were *nigritulus.*

August 23d, explored the region between Oyster creek, Newark bay and Sloping creek. The meadows here slope and the high tide covers a lot of ground. But it all drains clear at the ebb and there are few holes or pools. No mosquito larvæ were found on this day.

Twenty adult *sollicitans* were sent in, none of which showed developed ovaries, and only two of which showed traces of food in the gut.

August 25th, went to the piece of ground lying between Woodruff creek, Great island and the branch of the Central railroad leading to the Elizabeth race-course. Along a farmer's road, from the almshouse to Great island, are a number of pools, in which no larvæ were found except near Woodruff creek. No others were found until nearing Bound creek, where there is a small danger point, which can be easily drained into Bound creek.

The larvæ taken this day were mostly *territans* and *nigritulus;* one vial contained a brood of very recent *sollicitans* larvæ.

August 26th, worked on the south side of Woodruff creek, west of the Central railroad, to the farmer's road. Between the railroad and the road is the worst breeding place yet found. It is close to the upland and could be easily filled from the highland or drained into the creek. The ground is full of holes and ditches, but the ditches are filled only at extra high tides, and as they do not allow all the water to run off, they really make the worst sort of breeding places. Only a few of the holes and ditches had any fish.

The larvæ collected in this area by Mr. Brehme are mostly *nigritulus,* only a few *territans* being intermingled. Most of the larvæ were full-grown, or nearly so, and there were many pupæ as well.

A large series of adults was collected this day, including *sollicitans, cantans, sylvestris, nigritulus* and *territans.*

Of the *sollicitans,* fifty-one examples had no food in the alimentary canal and the ovaries were in nowise developed; four had fed on blood of some kind, yet had undeveloped ovaries; only one, showing no food remnants in the alimentary canal, had nineteen more than half-grown ova.

August 27th and 28th, covered the ground west from the farmer's road to the Catholic cemetery, finding wrigglers all along the edge of the meadow, in the pools formed there. This entire area should drain into Woodruff creek.

August 29th, completed the work along the edge of the meadow to the Pennsylvania railroad line at Waverly. Larvæ were found along the edge of the meadow in every pool and ditch. There is a wide ditch running in from Bound creek which can be made of service in draining this area.

August 30th, examined the meadow area near the Pennsylvania railroad, between Peddie Street canal and Wheeler's creek, finding no wrigglers anywhere.

Most of the larvæ brought in from this area were *nigritulus,* with a scattering of *territans* intermixed. In all, there were twenty-two vials in the series of edge of meadow collections; in only three of these were there short-tube larvæ, less than half-grown, which were probably *sylvestris.*

Fourteen bottles of living larvæ were also brought or sent into the laboratory from the same ground, and some adults were bred out of all of them. In all cases the water was at least brackish, and in most it was decidedly salt—even to the taste—as much so as the bay itself. The water in each bottle was tested by the tongue to make this positive.

By far the greatest number of adults bred were *nigritulus; territans* coming in far behind, while a few *sollicitans,* and about as many *sylvestris,* completed the series.

Of the adults collected on the meadow on the 27th there were a few each of *sylvestris* and *cantans,* quite a number of *territans,* and thirty-nine specimens of *sollicitans.* None of the latter had the ovaries at all developed and only three of them had fed, if absence of food remnants can be relied upon.

August 28th, sixty-five examples were sent in, and of these, eighteen were *nigritulus,* one was *sylvestris* and the remainder were *sollicitans.* Of the latter, nine had more or less obvious blood clots or particles in the alimentary canal, and of these, six contained ova less than half-grown. One example, in which the food had been pretty well absorbed, had the eggs more than half-grown, while one other, in which the abdomen was distended with eggs, had no food remnants at all.

September 1st, went by boat to Sloping creek, working inland from it and from the bay shore. Larvæ were found in a few places well up on the meadow, near the creek banks. The land is rather high, and the wet area would drain easily into Sloping creek. Some work has been done here by Senator Kean, and when the improvements contemplated by him are completed this breeding area will disappear.

Two vials of larvæ were sent in, of which one contained a large number of *nigritulus* only; the other contained eleven *nigritulus,* one *territans,* one *sollicitans.* The adults were, *nigritulus,* eighty-seven, of which fifty-seven were males; *sollicitans,* five, of which two were males. Of the three females, one only had partaken of some vegetable food, while in none were the ovaries at all developed.

September 2d, worked west from Oyster creek to Stoffel creek, which is really only a wide ditch. On the edge of this creek, near the mouth, I found a few pools with wrigglers, but the place is not very bad. Most of the time it is entirely dry, and, as it lies high, it can be easily drained into Stoffel creek.

Of the larvæ sent in all save two were *sollicitans,* and some of these were very small, indicating a recent extension of the pools. The odd larvæ were *territans.*

Of the adults sent in eighty-eight were *nigritulus,* and of these fifty-two were males. There were five *sollicitans,* of which two had remnants of blood food, one of the latter having the abdomen distended with ova that were more than half-grown. The interesting feature in the adult sendings from this region is the predominance of *Culex nigritulus,* which finds in the pools on the high meadows and at the borders of the upland the conditions most suited to it. As the adult of *nigritulus* very closely resembles that of *pungens,* it is more than probable that some of them may, if they get into the town, be counted in with the common species. There were also three specimens of *Anopheles maculipennis.*

September 3d, looked over the stretch along Peddie Street canal and along Dead creek, working towards the upland. A breeding area was found just at the junction of the creek and canal, which can be very completely drained into Dead creek by just cutting through the bank.

In the two vials of larvæ sent in all were *Culex nigritulus.* Among the adults there were two male and five female *sollicitans,* only one of which had fed and none that had the ovaries at all developed. *Culex nigritulus* was represented by twenty males and forty females, while *Anopheles maculipennis* turned out fifteen males and forty-three females. The occurrence of *Anopheles maculipennis* in such numbers and in both sexes points to a local breeding place. Mr. Brehme's instructions did not include search for *Anopheles* larvæ, and the habits of that genus differ sufficiently from those of *Culex* to make the former easily overlooked when the latter only was in view. The occurrence was not unexpected, however, because larvæ were found on this meadow area last year (1901) by Mr. Dickerson.

September 4th, followed the canal to Pierson's creek and beyond it to the Central railroad, and covered the territory northward to the Lehigh Valley railroad. Larvæ were found only along Pierson's creek, toward Maple island and just southeast of the railroad crossing. These areas can be drained into Pierson's creek in one case and into the Lehigh Valley railroad ditch in the other.

All the larvæ sent in were *sollicitans* and most of them were very small. Only one pupa occurred, and it could not be determined what species that represented. The collection of adults consisted, primarily, of *Culex nigritulus,* 115 males and forty females. Next came *Anopheles maculipennis,* twenty-four males and ten females; and lastly, only four *Culex sollicitans,* none of which had either fed or begun to develop ova.

September 5th, covered the ground between Bound creek, Maple creek, Newark bay and the Central railroad. In this area breeding pools are numerous and larvæ plentiful. There are a number of ditches through this place, but they are not properly placed, not deep enough and do not drain the water. The land is too high for ordinary tides, and there are no fish even in the ditches. Relief here would be by deeper ditches into Bound and Maple creeks.

Five vials of larvæ, containing about 150 specimens, were sent in, and all were *sollicitans.* They ranged in size from very small to nearly full-grown. The adults sent in were *Culex nigritulus,* ten males and thirty-one females; *Anopheles maculipennis,* six males and twenty females; *Culex sollicitans,* two females, neither of which had either food remnants or developed ova.

September 6th, on the night from the 5th to the 6th there was an extra high tide that flooded the meadows and left pools all over the covered area in every depression that could not drain off readily. It was the water-supply for which millions of eggs on the meadow had been waiting!

On that day covered the area between Maple creek, Peddie Street canal and the Central railroad. Wrigglers were found in pools along a ditch filled with "killies;" but unfortunately there was no connection between the ditch and the breeding pools.

Four vials of larvæ were received, all of them *sollicitans* and many of them not twenty-four hours old. Of the adults there were *Culex nigritulus,* eleven males and forty-eight females; *Anopheles maculipennis,* twenty-two females; *Culex sollicitans,* five females, none of which had obvious ova, while two had fed on blood.

September 8th, worked on a piece of land lying between the Passaic river, the Central railroad, Hamburg Place and the Newark and New York railroad. This was the worst place thus far discovered, and wrigglers were there in millions. The area is a piece of what I have called rotten marsh and ideal for mosquito multiplication.

Eight vials of larvæ were sent in, containing in the aggregate 630 specimens, all of them *sollicitans.* With few exceptions, these specimens were less than half-grown.

September 9th was an unfit day and brought to head another experiment begun on the 1st, when Mr. Brehme allowed one dozen *Culex sollicitans* to gorge upon his blood, capturing each individual in a separate vial and afterward turning them loose in large jars at his home. On the 8th all were dead, and on the 9th were bottled and sent to me. Three had fallen into the water dish in the prison jars and were not sent. Of the remainder, six did not show any blood remnants in the alimentary canal, and in none had the ova begun to increase in size. The other three were equally devoid of food remnants, but in two the ova were more than half-grown, and in the third the eggs were full-grown and getting into the transparent gray stage.

The experiment did not result quite as I had hoped, but showed at least that in a period of seven days a full blood-meal can be completely digested and excreted.

September 10th, continued the exploration of the area entered on the 8th, and toward the mainland it grew ever worse, the pools being simply black with larvæ. Mr. Brehme said he had never seen larvæ so abundant before—in a dip with his little coffee-strainer, he obtained twenty to twenty-five each time—with his net he could get a pint of larvæ at a single stroke. Another point noted was that, while larvæ were very plentiful, adults were rare and not at all troublesome. A ditch, with a strong flow of water, runs within fifty feet of the worst of this area.

Ten vials of wrigglers were sent in, all of them *sollicitans,* few of them much more than half-grown and aggregating a little over 1,000 specimens.

It was at this time, when the uniform size of the larvæ from so large an area attracted attention, that I began to inquire what had happened a few days ago and learned of the heavy tide of the 5th inst.

September 11th, found conditions south of Hamburg Place not quite so bad as on the north, but yet with numerous areas of the same general character. After determinating this point went to Pierson's creek, about a mile to the south, to see if there were larvæ in the pools filled by the tide on the 5th. There were wrigglers there, but also "killies," and very few were collected. These were separately tubed and turned out—*sollicitans,* ten, mostly small; *nigritulus,* six, mostly large.

The larvæ collected on the 11th were in fourteen vials and aggregated 1,277 specimens, of which two were separated as probable *sylvestris,* and all the others were *sollicitans.* Adults were reported as rare at this time, and the captures for the 10th and 11th numbered only fifty-three, of which six were *nigritulus.* Of *sollicitans,* there were twenty-one males and twenty-six females, and of the females, seven had the ovaries entirely undeveloped. In fifteen the eggs were less than half-grown and no food remnants could be found; in one specimen, in which the ovarian development was about the same, there was an appearance of vegetable food, and in two others, where the eggs were much less than half-grown, traces of blood were obvious. One other example had eighty-nine just countable eggs and no appearance of recent food.

September 12th, continued the exploration south of Hamburg Place to the bay and wrigglers were found in every pool. Eight vials were brought in, all *sollicitans,* but now beginning to pupate; in all, 436 specimens, of which twelve were pupæ. Adults were all *sollicitans,* forty-three males and sixteen females. Of the latter, eleven had not fed, nor had ovarian development begun; in four the eggs had begun to grow, but no food was found; in one example, in which the ova were half-grown, remnants of blood food were identified.

September 13th, Mr. Brehme collected and brought to New Brunswick some jars of living wrigglers from the Hamburg Place area. He reported that the larvæ were now full-grown and that the change to pupal form was becoming general; a statement borne out by his specimens. He added, also, that the breeding pools were becoming smaller and, unless refilled, could not last many more days.

I was not quite satisfied, after discussing the matter with Mr. Brehme, that the area first examined in August was always so free as he had found it at that time; so, as there had been a high tide and two heavy rains of late, he went again over the region between Woodruff creek, Oyster creek, Newark bay and the Central railroad. The meadows were very dry, even after the heavy rain on Saturday

(13th), and very few pools were found. The first larvæ were found near Wood creek, in one of a series of pools, and this was the only one that had no fish. No more wrigglers were seen until another pool area was found, near Oyster creek. Here a pool, 7 x 3 feet, was filled with them, but they had only about three-fourths to one inch of water and mud, which would be entirely dry in twenty-four hours, long before the larvæ could possibly reach the pupal stage. Similar conditions were found in a number of other pools. The pool first found is only about twenty feet away from a tide ditch containing fish, and fish were in pools 100 feet away. Mr. Brehme's conclusion is that this place cannot become bad in an ordinarily dry season because all the larger, more permanent pools are connected by little channels with main ditches and always contain fish.

All the larvæ sent in were *sollicitans.* Of the adults there were twenty-one male and twenty-one female *Culex nigritulus;* tweve female *Anopheles maculipennis,* and a few *Culex sollicitans,* which, by accident, were not counted or examined.

September 16th, I visited the Hamburg Place area with Mr. Brehme, and found the pools fast disappearing, while pupæ rather than larvæ were the rule. On the 11th and 12th Mr. Brehme had noted the rarity of adults; on the 16th they simply swarmed and made continuous fanning necessary to keep them off. The number was constantly increasing, and males as well as females were present in great quantity. It would be difficult to estimate the number of specimens bred out of this Hamburg Place area, and I doubt whether it can be done in terms of less than eight or even nine figures.

This case, however, illustrates the occurrence of a typical swarm. The period preceding September 5th had been dry and hot, and the meadow was dry, the adult mosquitoes few in number and dying off as their eggs were laid.

The very high tide of the 5th brought in the necessary water, soaked the marsh and left many pool areas without fish, in which eggs at once hatched and larvæ were already present on the 6th. Pupation began on the 12th and 13th, and by the 16h the great bulk was in the adult condition. Until this tide came the meadow was safe, and had there been any provision for even slow drainage, it would have remained so. The occurrence of two days of heavy rain probably prolonged the life of many pools sufficiently to enable them to mature their crop of larvæ.

In the afternoon Mr. Brehme made a preliminary exploration along the north bank of the Elizabeth river, near its mouth. He found there conditions as bad or worse than those on the Hamburg Place area. The character of the meadow is the same and the stage of development was also the same. Quite evidently, the same tide that supplied Newark was equally good to Elizabeth. Mr. Brehme speaks of adults by the million, and determined at once that to the south Elizabeth had a much greater source of danger than to the east.

I wrote a brief note of this occurrence to Dr. Robinson, at Elizabeth, and predicted that the next south wind would fill the city with salt marsh mosquitoes. It was a safe prediction, and was promptly verified.

Of the few larvæ taken all save three were *sollicitans;* the three oddities proved *nigritulus.* The adults were two male and five female *nigritulus;* eleven male and nineteen female *sollicitans.* Of the latter fifteen had undeveloped ovaries and no food remnants; one had a blood clot filling, but no developing ova; two had developing ova, without obvious food remnants, and one had the eggs half-grown, with remnants of blood food in the alimentary canal.

September 17th, worked along the Passaic river, between the plank road and the Newark and New York railroad. This place is well drained and wrigglers were found in only one pool, which was fast drying up. Worked, also, along the south side of the railroad, where nothing but cat-tails grow, and went through the whole place, just to see if mosquitoes do breed in such places, but found not even a sign of a wriggler.

Only two *sollicitans* and two *nigritulus* larvæ were sent in, but there were about thirty pupæ and pupa shells, probably *sollicitans.* Of the adults one male and eight females were *nigritulus;* thirteen males and seventeen females were *sollicitans.* Of the female *sollicitans* nine had neither eggs nor food remnants apparent; two had blood food, but no developing ova; three had the ovaries increased in size, but were without food; two had remnants of blood food and ova two-thirds-grown; one, in which the alimentary canal was clear, had the eggs full-grown. the shell becoming gray, translucent.

September 18th, finished up the north end of the Newark meadow, north of the plank road, and found it safe and well-drained. There was only one small pool that fills at extra high tide, and this had a few wrigglers.

In the afternoon revisited the territory explored September 5th, to see if it was as bad as it was then; found that it was, and that all the pools were full of larvæ. This is a continuous breeding area, and the meadow is comparatively low and wet.

Of the larvæ sent in—the vial from the north meadow area—one was *sollicitans* and five were *nigritulus*. The afternoon's collecting was all *sollicitans*, consisting of 112 larvæ and fifty-one pupæ. The adults were *Anopheles maculipennis*, three males; *Culex nigritulus*, two males and three females; *Culex sollicitans*, sixteen males and twenty-four females. Of the female *sollicitans* sixteen showed neither food nor developed ova; four had eggs varying from half to nearly full-grown, without food remnants; one had a blood-distended abdomen, containing no developed eggs, and three had remnants of blood food, with eggs half-grown or more.

September 19th, worked along the north side of the Elizabeth river, west of the New York and Long Branch railroad, and found two rather bad breeding areas, but not so bad as those at the mouth of the river. This area can be very easily drained into the Elizabeth river.

All the larvæ and pupæ, 217 in number, were *sollicitans*. The adults—thirteen males and nineteen females—were also *sollicitans*. Of the females twelve had neither food nor developing ova; two had developing ova, without food remnants, and five had eggs half-grown or more, with remnants of blood food.

September 20th, explored the territory lying on the south side of the Elizabeth river and east of the New York and Long Branch railroad. This is not so bad as the north side of the river, but many pools were found in which wrigglers occurred in great quantity. The whole of this area drains naturally towards the Elizabeth river.

Of the larvæ sent in thirty-two were *sollicitans* and five were *nigritulus*. Of the adults one male and two females were *nigritulus* and eleven females were *sollicitans*. The latter, to all appearances, had neither fed nor had they developed ovaries.

September 21st was Sunday, and Mr. Brehme went fishing instead of hunting; but he combined business with pleasure, and made one of the most important observations of his season. I give it nearly as he states it: "I was down the Bound creek yesterday, fishing for tomcod. When I went down along Maple creek at 6 A. M. I saw a pool that was filled with wrigglers. I noticed that we had one of the highest tides that I have seen since 1895, so I thought, while fishing, that it would be a good idea to make a search over the meadows and see if any 'killies' were thrown in on the highest points between Maple and Bound creeks. After I got through fishing, when the tide had run out five hours and the fish did not bite any more, I took a look at the places. To my surprise, I found the places that were nearly dry this morning filled with water and hundreds of 'killies' in the pools. I looked closely, to find the wrigglers which I had seen only nine hours before, but did not find even one. In the one pool where I had seen so many there were at least 200 'killies.' So, draining this place just a little would certainly do away with the mosquito breeding."

September 22d, worked along the south side of the Elizabeth river, west of the New York and Long Branch railroad. It is certainly a bad spot, and quite a number of pools containing wrigglers was found. But the water was again unusually high, and the meadows were so deeply covered that progress was slow and many points could not be reached at all.

Of the larvæ sent in two vials contained *sollicitans* only; the third contained twenty-one *sollicitans* and five *nigritulus;* the fourth had twelve examples of a species very like *sollicitans,* but which I recognized as distinct. Later, I bred from this larva an adult, that was determined as *sylvestris,* and so the species will be referred to here. There was also a larva of *Anopheles maculipennis* in this fourth bottle. The adults taken were *nigritulus,* three males and two females; *sollicitans,* ten males and sixteen females. Of the female *sollicitans* eleven had not fed recently and the ovaries were undevloped; in one the ova had just begun to enlarge, though no food remnants were found, and in four there were half-grown ova and remnants of blood food.

September 23d, went along the south side of the Elizabeth river, from Arthur Kill west to the place reached on the 20th. This is another bad spot, and wrigglers were found everywhere, in every pool, even though it was very high water. During the day, though the meadow was everywhere covered by recent tide pools, very few "killies" were seen. Drainage of this area can be made to the Kill and to the river.

Three vials of larvæ sent in, and, with one exception, all were *sylvestris;* there was one *nigritulus.* Of the few adults taken three males and three females were *nigritulus;* eight females were *sollicitans.* None of the latter had the ovaries at all developed, though three had the abdomen distended by blood clots.

September 24th, worked along the west end of the Elizabeth river as far as meadow land is found. This area is not so wet as farther down, though there are many pools that seem just about right for wrigglers. Yet there are not so many there, and the place is not near so bad as down stream. And this completes the survey of the area at the mouth of the Elizabeth river.

Three vials of larvæ were sent in, and all save three were *sylvestris*. Of the three, two were *nigritulus* and one was *sollicitans*. Of the adults, four males and two females were *nigritulus;* twelve males and thirteen females were *sollicitans*. The female *sollicitans* showed neither food remnants nor developing ovaries.

September 25th was a very rainy day, and Mr. Brehme gave it up at 1 P. M., when thoroughly soaked. The time was put in near Morse's creek, about one mile south of the Elizabeth river. There were numerous pools here filled with very small wrigglers, only two or three days old, and, while the day was not favorable for close observation, enough was seen to show that this area is ideal for mosquitoes. There are a number of large ditches through it, and into these and the creek the land could be readily drained.

Four vials of larvæ were sent in, each taken from one pool and showing quite a variety. No. 156 had *sollicitans,* twenty-nine; *territans,* three; *nigritulus,* nine; *sylvestris,* seven. No. 157 had *sylvestris;* seventeen; *nigritulus,* one; *sollicitans,* three. No. 158 had *sollicitans,* thirty-three (all small). No. 159 had *sylvestris* only. Of the adults, one was *Anopheles maculipennis,* male; there were one male and two female *Culex nigritulus;* fourteen male and twelve female *sollicitans*. Only one female *sollicitans* showed developing ova, and this was also the only specimen in which food remnants were found.

September 26th was too stormy for even Mr. Brehme to venture out, and on the 27th he covered a thertofore unexplored part of the Newark meadow, between Peddie Street canal and Bound creek, east of the Pennsylvania railroad. No breeding places were found in the accessible parts of this area; but recent high tides and heavy rainfall had flooded everything and a large portion of the meadow was covered by from four to six inches of water.

September 29th, covered the territory on the west side of the New York and Long Branch railroad, on both sides of Morse's creek, down as far as Morse's Mills. The pools found during the morning all had "killies," and no wrigglers were found; but after midday, working ing in toward the highlands they were found in numbers. Working along the meadows, found wrigglers, large and small, in great numbers, and at least three kinds. At least 95 per cent. of the larvæ are small and they are scattered everywhere and everything is covered with water. When the water gets down to its normal condition there will be wrigglers by the million, and this will be the largest brood of the season.

Seven vials were sent in, containing over 200 larvæ. Of these, four were *Anopheles maculipennis,* two were *Culex territans,* fourteen were *C. nigritulus* and all the rest were *sollicitans,* mostly small or very small.

Evidently the high water and heavy storms of the preceding week had caused the hatching of all the eggs then on the meadow. Adults of the preceding brood were yet present "by the million" and 108 examples were sent in. Of these, four were *nigritulus* and all the rest *sollicitans*; forty-nine males and fifty-five females. Of the latter, thirty had neither food remnants nor developing ovaries; eight had recently fed upon blood, and the ovaries were beginning to develop; eight others had remnants of blood food only, and the ova were half or more developed. In seven examples, the eggs were nearly or quite full-grown, but yet white, and in three of these remnants of blood food were found.

September 30th, a large area was covered extending between Arthur Kill and the New York and Long Branch railroad, from Morse's creek to a creek not named on the map, and west of the railroad to the upland. In the entire area east of the railroad only two small breeding pools were found, and these can be easily filled from the highland right there. West of the railroad larvæ were again found at the edge of the upland.

On the return, a lot of living larvæ were collected on the area covered September 23d, and these were sent to me that I might secure adults of the *sylvestris* breeding there. Mr. Brehme notes that the larvæ were much reduced in number and that the high tides since his previous exploration had thrown at least 100 per cent. more "killies" into the pools.

Five vials of larvæ were sent in, containing 147 specimens. Of these, three were *territans,* six *nigritulus,* and all the others *sollicitans.* Of the adults all were *sollicitans;* forty-four males and thirty-nine females. Of the females, twenty-eight had neither food nor developed ova, nine had food remnants, with eggs half-grown or less, and two had the eggs fully developed, beginning to turn gray, and no trace of food remnants.

October 1st it was raining, but Mr. Brehme worked on the south side of the unnamed creek, both east and west of the railroad. East of the railroad nothing was found, nor was any breeding place discovered on the west side until the edge of the highland was reached. This territory has been ditched at some time, and the breeding places that remain can be easily drained into these ditches or into the large creek.

Six vials of larvæ were sent in, aggregating 147 specimens. Of these, twenty were *territans,* twelve were *nigritulus,* and the remainder were *sollicitans,* many of them small and with possibly some *sylvestris* intermixed. Of the adults, fourteen males and ten females were *nigritulus;* twenty males and sixteen females were *sollicitans.* Of the latter, eleven females had not fed, to all appearance, and the ovaries were undeveloped. Five had fed, but in only one example had the eggs begun to enlarge.

October 2d, covered the territory between the Sound Shore railroad and Tremley. In the low meadows no wrigglers were found; but along the highland there were plenty of them. This area has two creeks, the Arthur Kill and several ditches to carry off the breeding pools.

Eight vials of larvæ were sent in, aggregating 204 specimens. Of these, five were *territans,* seventy-three were *sollicitans* and the remainder were *sylvestris.* Of the adults, five males and fourteen females were *nigritulus* and twenty-two, all females, were *sollicitans.* The latter were not examined as to food or ovarian development.

October 3d, finished the lower corner of the meadow about Tremley, to the Rahway river. One little breeding area was found on the Sound Shore railroad, and the usual areas along the highland. This portion of the meadow drains into the Kill or into the Rahway river.

Eight vials of larvæ were sent in, aggregating 297 specimens. Of these, one was *territans,* one was *nigritulus,* eleven were *sollicitans* and all the remainder were *sylvestris.* The *sollicitans* and *nigritulus* were taken near the Sound Shore railroad, and all the others along the highland.

October 4th, collections were made along the Elizabeth river, and a lot of living material was secured for me. Two vials of larvæ were collected in alcohol, and all of these were *sylvestris.* The living material, however, bred out *sollicitans, sylvestris* and *nigritulus,* the former being in the minority, with eighteen adults as against sixty-three of the others.

Besides the living material actually mentioned, Mr. Brehme sent in other bottles from time to time. Mr. Dickerson came daily from Newark to New Brunswick, and Mr. Brehme met him at the railroad station with such material as was to be brought on. I was thus in constant communication with Mr. Brehme, and as soon as I noted any unusual form of larva in the alcoholic material could secure a lot of living specimens from the same area. Mr. Brehme also gathered in some of the natural enemies living in the same pools with the wrigglers, but as any close collecting would have consumed too much time, very little stress was placed on this point.

The survey was intended primarily to locate breeding places and to ascertain just how much of a task is really before us in our effort to clear the ground. I believe that the result is decidedly encouraging and shows that the burden will not be nearly so great as was believed. Several scientific questions were left unsettled because of the impossibility of continuing the work after October 4th, but this does not impair the practical result obtained.

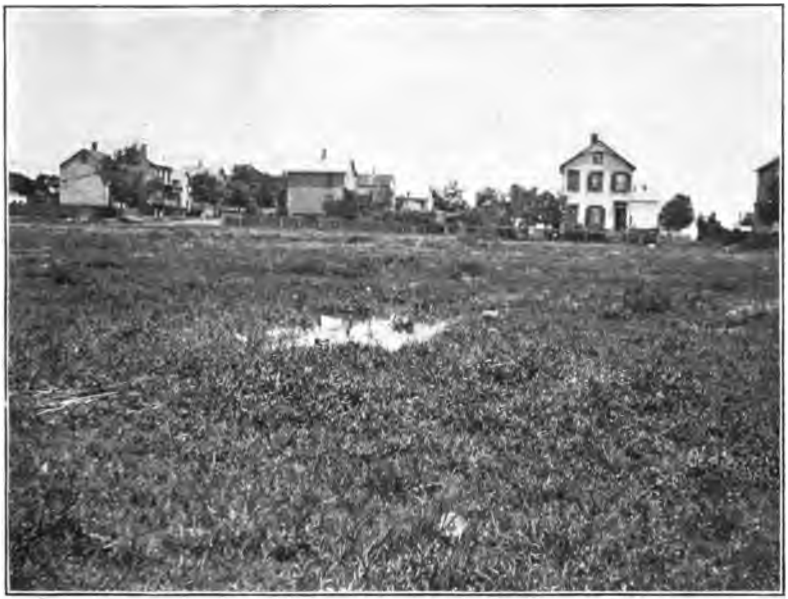
One further word regarding the collections: It would have been possible, of course, to secure much greater numbers of larvæ in each case, but Mr. Brehme was instructed to merely sample characteristic pools in each breeding area, that the dominant species in each locality might be indicated; and so, in the collection of adults, only enough were taken to show what species were flying.

A very important outcome of the survey is the fact that *Anopheles maculipennis* occurs on these marshes in considerable numbers and breeds there. This is the species of which it has been definitely proved that it is a transmitter of malarial fevers, and any large establishments built on this area before it is drained would almost certainly introduce malaria in an unpleasantly epidemic form.

Elizabeth City Collections.

At my request, Mr. Otto Buchholz, living on Adams avenue, Elizabeth, collected for me at intervals of about five days, from June 20th to October 19th, samples of the mosquitoes occurring in and about his house. The objects were to ascertain—*first,* the dominant species of the year; *second,* whether the same species occurred in equal proportions indoor and out. Therefore, the specimens collected in the house were kept carefully separated from the others, and the outside collections were made near to the house itself. The following lists are instructive:

Fig. 5.



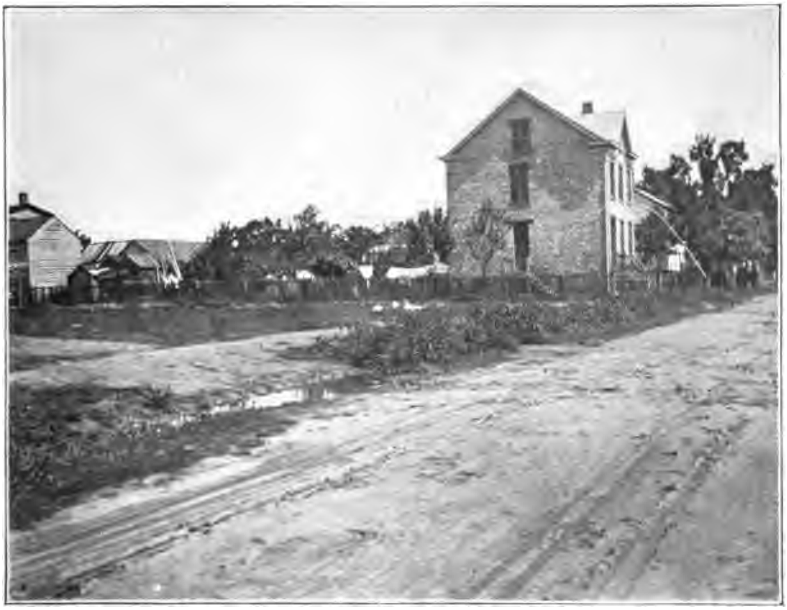


Fig. 5.

Mosquito Breeding Places in New Brunswick The upper figure shows a typical vacant-lot pool from which thousands of the insects emerge, and which could be easily filled; the lower figure shows a neglected gutter, partly overgrown and forming pools in which water remains for weeks. From original photographs.

Out-door Collections.

June 20.	Culex sollicitans, all females	40	
	" cantans, all females	4	
	" pungens, 5 males, 5 females	10	
			54
" 25.	" pungens, 109 males, 2 females	111	
	" sollicitans, all females	6	
			117
" 30.	" sollicitans, all females	12	
	" pungens, 1 male, 17 females	18	
			30
July 5.	" sollicitans, all females	24	
	" pungens, 29 males, 6 females	35	
	" cantans, all females	4	
			63
" 10.	" pungens, 118 males, 18 females	136	
	" sollicitans, all females	8	
			144
" 15.	" pungens, 16 males, 8 females	24	
	" sollicitans, all females	5	
			29
" 20.	" pungens, 22 males, 27 females	49	
	" sollicitans, all females	4	
			53
" 25.	" sollicitans, all females	4	
	" pungens, 3 males, 14 females	17	
			21
Aug. 5.	" sollicitans all females	20	
	" sylvestris, all females	11	
	" pungens, all females	2	
			33
" 10.	" sollicitans, all females	19	
	" sylvestris, all females	5	
	" pungens, all females	4	
			28
" 15.	" sollicitans, all females	26	
	" sylvestris, all females	16	
	" pungens, all females	3	
	Anopheles punctipennis, females	2	
			47
" 20.	Culex sollicitans, all females	12	
	" sylvestris, 2 males, 12 females	14	
	" pungens, all females	4	
	Psorophora ciliata, female	1	
			31
" 25.	Culex sollicitans, all females	16	
	" sylvestris, 9 males, 46 females	55	
	" pungens, all females	6	
	" territans, female	1	
			78

Aug.	30.	Culex sollicitans, 1 male, 7 females	8	
		" sylvestris, all females	7	
		" pungens, 6 males, 29 females	35	
		Anopheles punctipennis, female	1	
				51
Sept	1.	Culex sollicitans, all females	6	
		" cantans, 7 males, 16 females	23	
		" sylvestris, 3 males, 2 females	5	
				34
"	5.	" cantans, all females	2	
		" pungens, 9 males, 1 female	10	
				12
"	10.	" pungens, 12 males, 5 females		17
"	15.	" sollicitans, all females	3	
		" cantans, all males	2	
		" pungens, all males	5	
				10
"	20.	" sollicitans, 2 males, 20 females	22	
		" sylvestris, 1 male, 4 females	5	
		" pungens, 15 males, 26 females	41	
		Anopheles punctipennis, female	1	
				69
"	25.	Culex sollicitans, 1 male, 7 females	8	
		" pungens, 5 males, 9 females	14	
		Anopheles punctipennis, female	1	
				23
"	30.	Culex sollicitans, 1 male, 2 females	3	
		" pungens, 5 males, 15 females	20	
		" cantans, 1 male, 2 females	3	
				26
Oct.	5.	" pungens, 2 males, 16 females	18	
		" sylvestris, female	1	
				19
"	19.	" pungens, 1 male, 34 females	35	
		" cantans, 1 male, 4 females	5	
				40
		Altogether		1,029

These specimens are divided, as to species and sexes, as follows:

Culex sollicitans,	males, 5;	females, 241	246
" cantans,	" 11;	" 32	43
" sylvestris,	" 15;	" 104	119
" pungens,	" 363;	" 251	614
" territans,		" 1	1
Anopheles punctipennis,		" 5	5
Psorophora ciliata,		" 1	1
			1,029

This shows strikingly that *pungens* is a local species, more than half of the specimens being males, while *sollicitans* is an intruder, only five males out of 246 specimens being taken during the season. *Cantans* and *sylvestris* breed closer by, and probably within the city limits.

From the large number of male *pungens* taken, it is probable that there is a local breeding point for that species close to where the collections were made, and that the species is unduly represented for that reason. It is also possible that some of the specimens called *pungens* are really *territans;* indeed, it is almost certain that such is the case, but the material examined was in alcohol and discrimination is not easy.

The list of indoor captures is as follows:

June 20.	Culex cantans	2	females.	
	" pungens	3	"	
	" sollicitans	2	"	
		—		7
" 25.	" pungens	5	"	
	" sollicitans	2	"	
		—		7
" 30.	" pungens	6	"	
	" sollicitans	1	"	
		—		7
July 5.	" pungens	5	"	
	" sollicitans	3	"	
		—		8
" 10.	" pungens	26	"	
	" sollicitans	1	"	
		—		27
" 15.	" pungens	17	"	17
" 20.	" pungens	11	"	11
" 25.	" pungens	13	"	13
" 30.	" pungens	20	"	
	" sollicitans	1	"	
		—		21
Aug. 5.	" pungens	22	"	22
" 10.	" pungens	14	"	14
" 15.	" pungens	22	"	22
" 20.	" pungens	18	"	18
" 25.	" pungens	16	"	
	Psorophora ciliata	1	"	
		—		17
" 30.	Culex pungens	17	"	
	" sylvestris	1	"	
		—		18

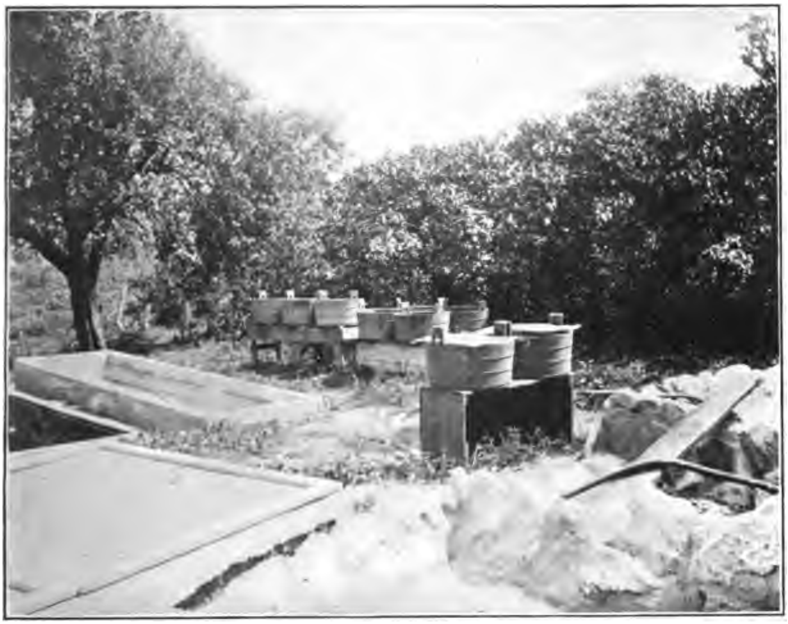
Sept.	5.	Culex pungens		6 females.	6
"	10.	" pungens		16 "	16
"	15.	" pungens		5 "	
		Anopheles maculipennis		1 "	
					6
"	20.	Culex pungens		10 "	
		" territans		6 "	
		Anopheles maculipennis		1 "	
					17
"	25.	Culex pungens		6 "	
		" sollicitans		2 "	
					8
"	30.	" pungens		10 "	
		" territans		7 "	
					17
Oct.	5.	" pungens		5 "	5
"	10.	" pungens	1 male,	3 "	
		Anopheles maculipennis		1 "	
					5
"	19.	Culex pungens	1 male,	8 "	9
		Altogether			318

Divided as to species, we get—

Culex pungens	286
" sollicitans	12
" cantans	2
" sylvestris	1
" territans	13
Anopheles maculipennis	3
Psorophora ciliata	1
Total	318

In other words, while outdoors the females of *pungens* and *sollicitans* were in almost equal numbers, only twelve *sollicitans* out of a total of over 300 were found indoors.

In all, 1,347 specimens were examined, and the justice of the title "house mosquito" for *pungens* is fully demonstrated. It is absolutely necessary, to secure indoor comfort, that the local breeding places of this species must be destroyed or treated. It is absolutely necessary, to secure outdoor comfort, that the salt marsh species be dealt with. As to the local breeding places in Elizabeth, the report made by Dr. Wm. F. Robinson to the organization that conducted the mosquito campaign in that city gives useful information. The sewer catch-basin as a mosquito breeder is very prominently brought out in that report, and this point is of great importance to any similar organization that may be hereafter formed to deal with local conditions.



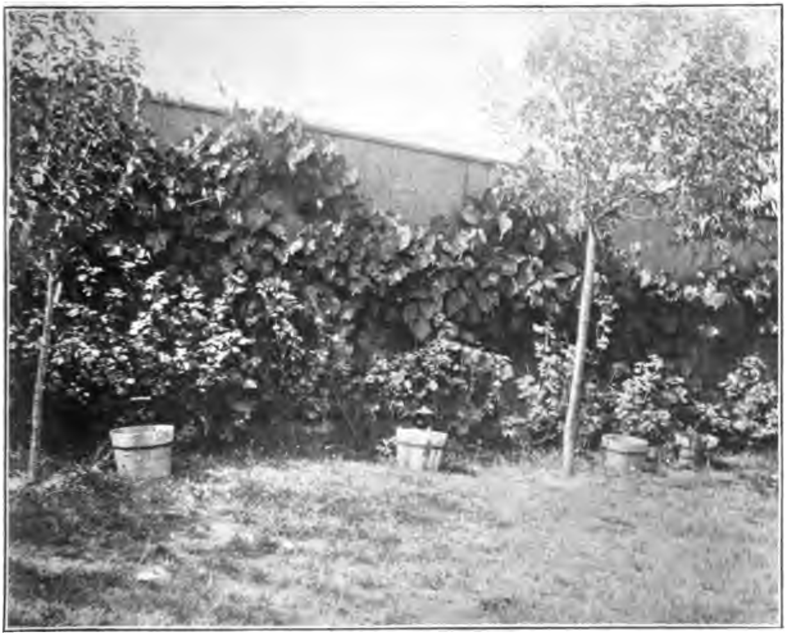


Fig. 6.

Upper figure represents the Experiment Tubs at Delair; the lower, the Breeding Pails at New Brunswick. From original photographs.

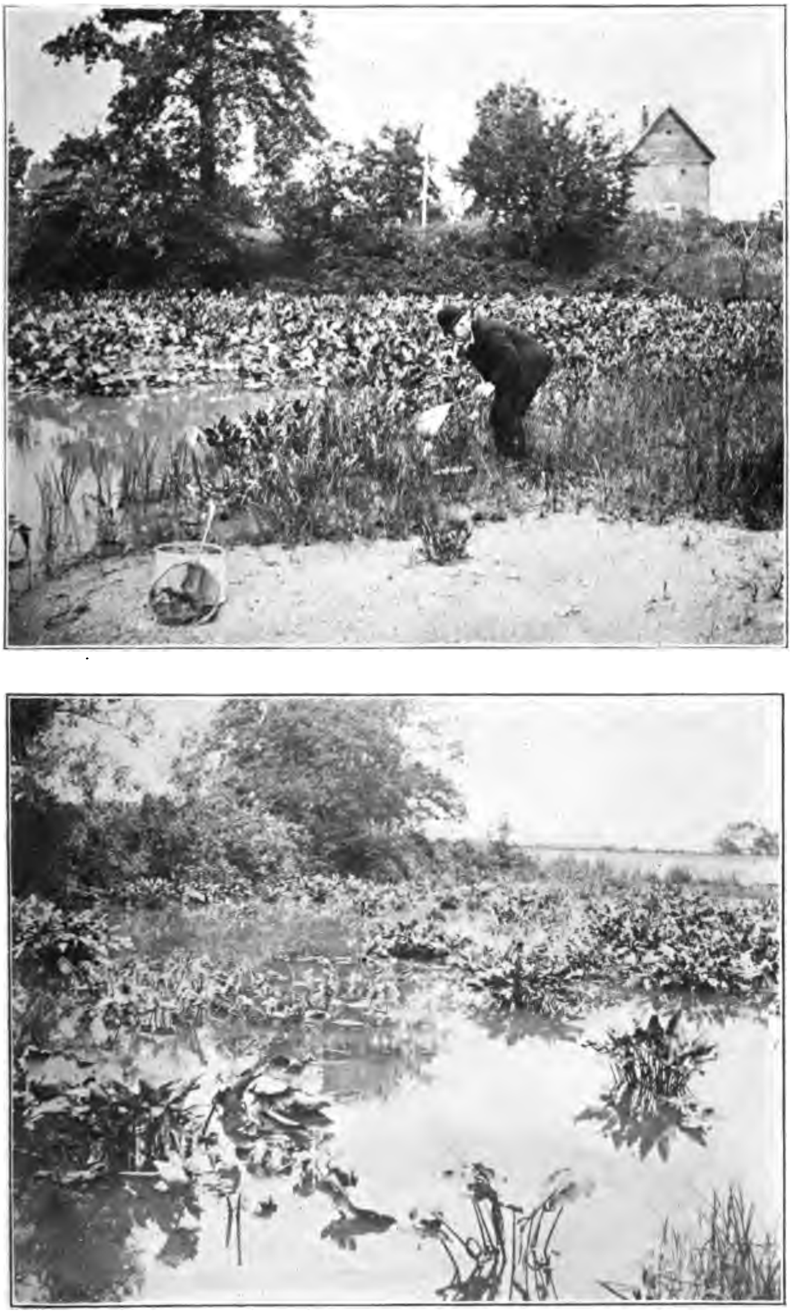
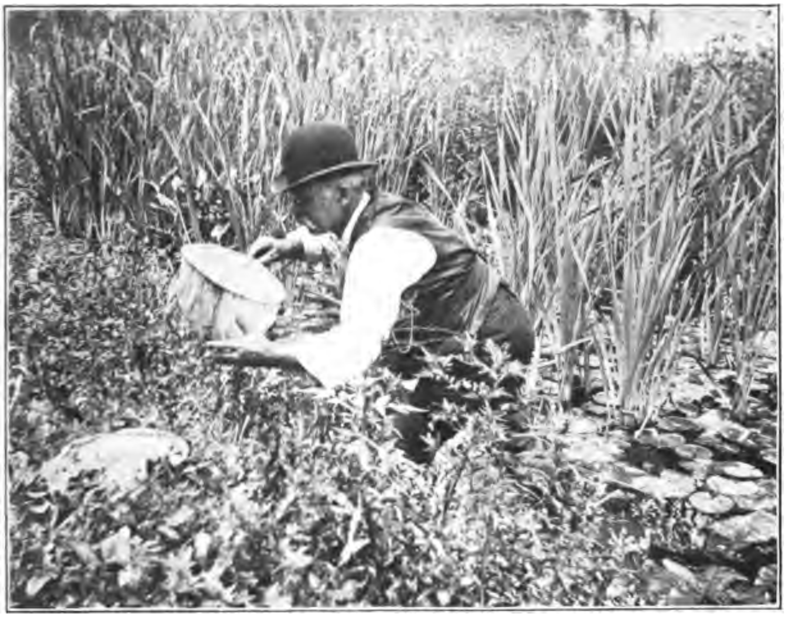


Fig. 7.

Breeding Places for Anopheles. In the upper figure Mr. Seal is standing in the shallow grassy margin where larvæ are numerous; the lower figure shows more open water, where fish can get freely and where few larvæ occur. From original photographs.



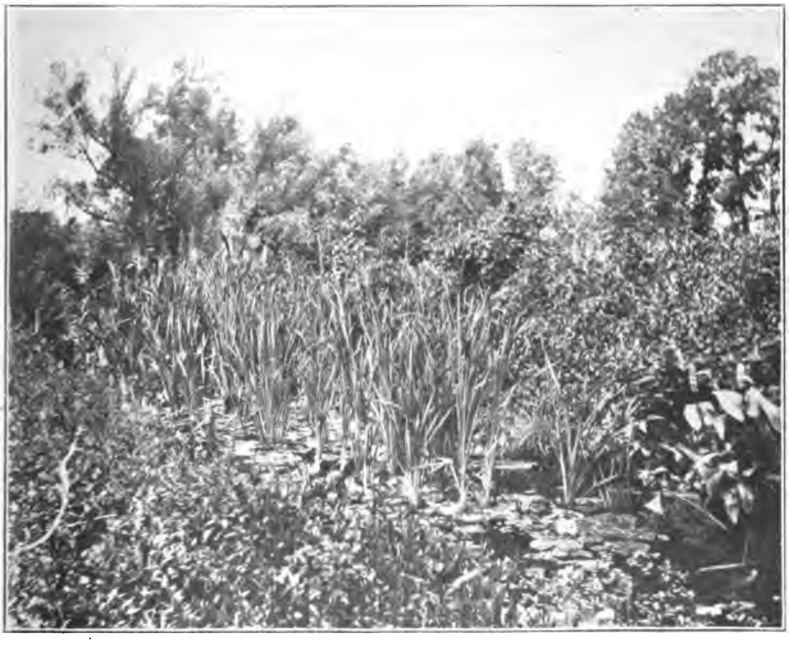


Fig. 8.

Open swamp area making excellent places for Anopheles breeding. The upper figure shows Mr. Seal among the rushes and lily pads collecting larvæ. From original photographs.

This particular sort of breeding place is easily dealt with by the municipalities where it occurs, and the process may include either actual disinfection or a mere oiling to stop breeding.

Drainage.

It has appeared again and again in this report that drainage, or ditching, is the method by which bad breeding areas are to be redeemed and made harmless. The matter of cost will always be an important consideration in all work to be undertaken; hence, when I learned that at Newburyport, Massachusetts, there was a practical machine for cutting drainage ditches in salt marshes, I went to that city September 2d, and saw Mr. Mark B. True, the inventor. Plate 9 gives a fair representation of the hand-power machine, as it now stands on the Salisbury marshes. This machine has been in service over twenty years and does good work yet; a much larger power machine was also seen, but in such position that it could not be photographed. This machine cuts ditches four to eight inches wide, two to three feet deep, at the rate of about forty to 100 rods per day, with a crew of four men, of whom two work the wheel and two move the tracks upon which the machine runs. Improvements recently made have improved its efficiency to such an extent that the persons owning the patents offer to take contracts for ditching at ten cents per rod. At this rate, areas like those about Newark and Elizabeth could be thoroughly drained for a few hundred dollars and the work would be done for good. Even such marsh areas as those at the mouth of the Mullica river lose their terrors, while such strips as those on the bay-side of the Barnegat island can be thoroughly freed of breeding places at a sum that would be made up by the increased hotel patronage in one season. This subject is scarcely ripe for final treatment at present, but the possibility of effective cheap ditching in necessary areas only, will bring the whole problem down to a simple business proposition. There is no question of the possibility of accomplishing the end—the only question is one of cost.

It is unfortunate, perhaps, that the owners of the True ditcher refuse to sell machines; they prefer to secure contracts to do the work, and, of course, will scarcely care to undertake to drain an area which is not large enough to make it pay to bring their machines down.

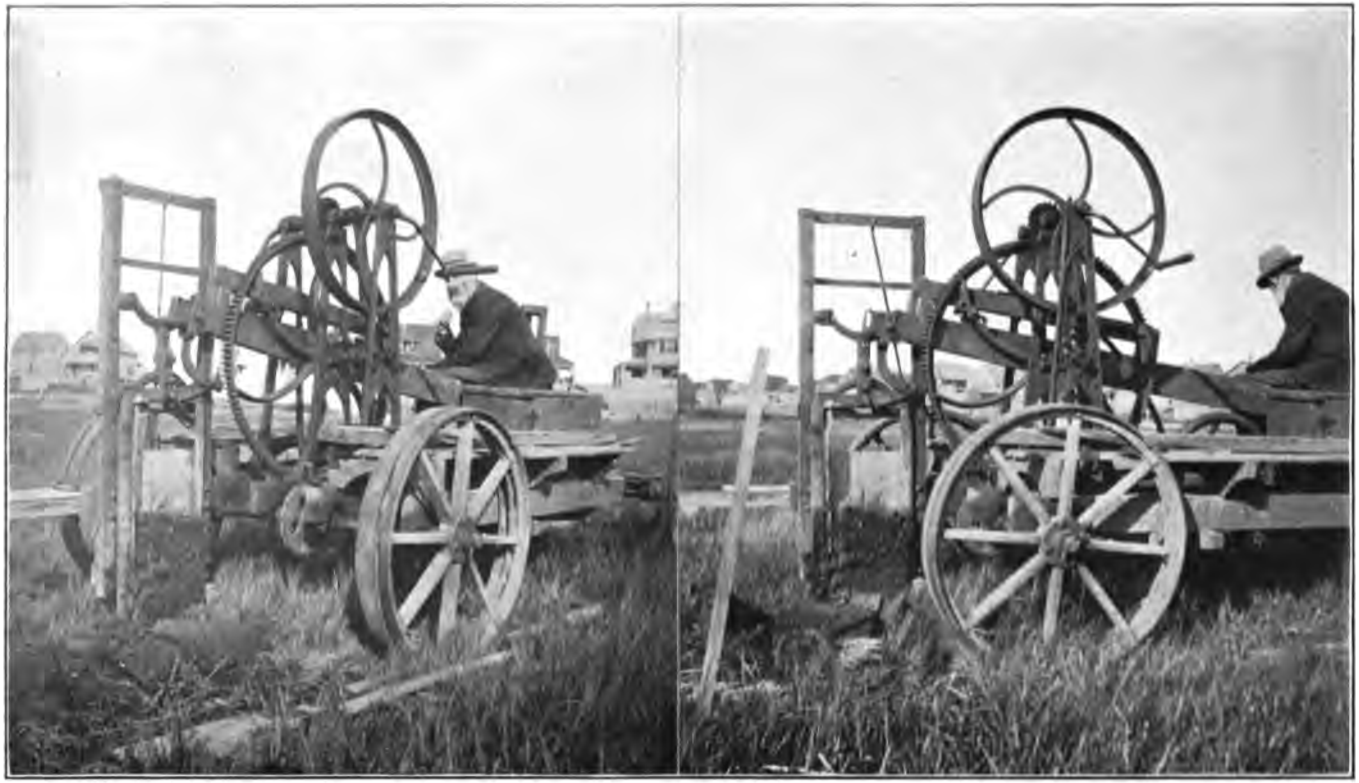


Fig. 9.

The True Ditcher from two points of view, showing a sod partly lifted out. From an original photograph.

APPENDIX A.

A STUDY OF CERTAIN MOSQUITOES IN NEW JERSEY,* AND A STATEMENT OF THE "MOSQUITO-MALARIA-THEORY."

HERBERT PARLIN JOHNSON, PH.D.

Introduction.

The following studies were undertaken as a part of the investigations conducted during the summer of 1902 by Dr. John B. Smith, with the object of devising ways and means of abating the mosquito nuisance and malaria in New Jersey. My subject was the relation between the prevalence of malaria and abundance of mosquitoes of the genus *Anopheles*, and the particular problem in hand was to determine whether *Anopheles punctipennis* is a carrier of malaria. The gathering of data regarding the breeding habits, distribution, etc., of our common mosquitoes also came within the scope of the season's work.

Of the three species of *Anopheles* found in New Jersey, only *Anopheles maculipennis* is positively known to be a carrier of malaria. *A. crucians* is practically ruled out on account of its extreme rarity. It remains, therefore, to ascertain what is the status of *A. punctipennis* in the malaria problem. This is much the commonest species of the genus in New Jersey, and in some localities is almost the only *Anopheles*. As it is found practically everywhere in the Eastern United States, it is a matter of hygienic, as well as of scientific, moment to find out whether it is capable of transmitting malaria. The only road to exact knowledge is experiment, and this is sure to be a path beset with difficulties. In fact, it is only by a concurrence of fortunate circumstances that such an experiment can succeed. Usually several attempts must be made before every condition is fulfilled. It is not surprising, therefore, that for the past season there is only a record of failure. The summer was exceptionally healthy, even in localities usually malarial. Very few cases of malaria were reported by the physicians who are co-operating in the experiment. Owing to continued unsuccess in New Jersey, in the early part of September I requested Dr. Wm. N. Berkeley to attempt it in New York with mosquitoes of my rearing, and he kindly consented. Although he had access to patients at the Bellevue and Presbyterian Hospitals, even there no opportunity offered. Never before had there been so few cases of malaria. Thus the experiment was completely balked.

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* Dr. Johnson's statements and conclusions concerning mosquitoes are his own, and the conclusions are not necessarily identical with my own in all particulars.

It is a pleasure to express my sincere thanks to the Harrison Board of Health for the use of one of their rooms as a laboratory; to Mr. John McClure, the house inspector of Harrison, for many favors; to Mr. Horatio N. Parker, the health officer of Montclair, for much friendly assistance; to Dr. R. N. Connolly, bacteriologist to the Newark Board of Health, for many laboratory favors; to Dr. William N. Berkeley, of New York, for generously assisting with the experiment, and to the many physicians of Newark, East Newark, Harrison, Kearny, Montclair and Verona, who took a friendly interest in the investigation.

The Species Met With.

No effort was made to form a comprehensive collection of mosquitoes or to determine how many species inhabit the limited region examined. The species which concern the public are obviously those which are abundant enough to be a menace to health or a source of discomfort. There were encountered but four of this description—*Culex pungens,* the common house mosquito, breeding in a greater variety of localities than any other species; *Culex sollicitans,* the ring-legged or salt marsh mosquito, an almost intolerable pest in and about the meadows, also on verandas and front porches after sundown; *Anopheles punctipennis,* fairly abundant during the latter part of the season, but only seen by me in the free condition as larvæ or pupæ; finally, *Anopheles maculipennis,* not abundant, but of great interest because the only one of our species positively known to be a carrier of malaria.

Mere mention is made of three other species—*Culex territans,* similar to *C. pungens,* but less common and local; *Uranotænia sapphirina,* a small, rare and very pretty species, twice met with; *Anopheles crucians,* a rare form closely resembling *A. maculipennis,* of which one specimen was reared from the pupa.

As of most interest in the present investigation, study was concentrated on the two species of *Anopheles,* especially upon *A. punctipennis,* some hundreds of which were obtained in the larval state, and scores were reared to adults. *Culex pungens* was also studied, but this was incidental. The species has received a good deal of attention at the hands of American Entomologists, and its near relative in Europe (*C. pipiens*) has also been carefully investigated by Kerschbaumer and others. Most of our knowledge of the life history of the genus *Culex* is based upon these two species. The reasons are obvious—they are both abundant and both are easily reared in confinement. Since the eggs are laid in good-sized bunches, known as "egg-boats," which float on the surface of the water, they are easy to find, and one can start from the egg in rearing experiments.

Of the four recognized and well-established species of *Anopheles* inhabiting the United States, the only one positively known to be a transmitter of malaria is *Anopheles maculipennis* (*A. quadrimaculata,* of many American writers; *A. claviger,* of German and Italian authors). Howard makes the interesting conjecture (1901,* p. 93) that "it is quite within the bounds of possibility that malaria was originally an European disease, and that not only was the disease tself carried from there on sailing vessels, but the mosquitoes which propogate it as well, at least to America."

Since our *Anopheles maculipennis* has been experimentally proven o be capable of serving as the transmitting host of the malarial oranism (Berkeley, 1902), it might seem a foregone conclusion that he other species of *Anopheles* are also susceptible. An acquaintance ith the life histories of animal parasites, particularly those of the ass to which the malarial organism belongs, shows that such reasong is apt to be fallacious. While highly probable, it is not certain; erefore, each species must be put to the experimental test.

It is a matter of importance from the sanitary standpoint to work t fully and in detail the distribution of *Anopheles* and ascertain to at extent its abundance is correlated with the prevalence of maia. Judging from the inadequate data available, it would seem

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The year of publication is used as a reference number to the literature-list at the of the report.

that our two commoner species often replace each other—*punctipennis* being common where *maculipennis* is rare, and *vice versa.* In New Jersey, *punctipennis* is the common species, while *maculipennis* is scarce. In New York City, as I am informed by Dr. Berkeley, *maculipennis* is the prevailing species. During the summer of 1901, Jordan (1902, p. 21) found, at Shelburne, New Hampshire, both *punctipennis* and *maculipennis,* but the latter decidely in the minority. "Only three individuals of *A. maculipennis* were raised from larvæ and pupæ captured during the season, as against thirty individuals of *A. punctipennis* from the same pools." My own experience in collecting adult mosquitoes at the Boston Parental School, West Roxbury, Massachusetts, during October and November, 1901 (Johnson, 1902, p. 213), was that *maculipennis* outnumbered *punctipennis* about ten to one.* It is interesting to note that at Forest Hills, only five miles from the Parental School, *punctipennis* is the prevailing species, while *maculipennis* is comparatively rare. (Theobald Smith, 1901.)

It is, of course, entirely possible that the relative abundance of the two species changes in the same locality from year to year. But neither seasonal nor local preponderance of one species or the other can have much significance until we know whether one species or both are carriers of malaria.

Meteorological Conditions.

Work began July 7th and closed September 17th. During this time the weather exhibited the usual variety of an eastern summer, but without a long "hot spell" and without a drought. The latter half of June had been unusually cool; this probably gave mosquito breeding a setback. Unfortunately, the temperature record is very incomplete. Daily observations were made only during a part of the season, from July 29th to September 16th. The air temperature of the laboratory was taken, also the water temperature in the aquaria. The highest temperature recorded was 30° C. (86° F.), and this but twice—August 4th and 6th. Temperatures between 26° C. (78° F.) and 30° C. were observed on nine days only—July 29th, August 5th, 6th, 8th, 9th, 11th, 18th, 26th, 27th and September 2d. A day temperature of 20° C. (68° F.) or lower was observed at no time during

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* In this case only females were counted, and, by actual count, the number of *A. maculipennis* captured was 248, of *A. punctipennis*, 25.

August and not until September 5th and 6th. When the dishes were in direct sunlight for some time the water temperature was as high as or a degree or two higher than the air temperature; otherwise, a degree or two lower (centigrade).

Breeding Conditions and Localities.

Of the conditions that favor the breeding of mosquitoes, especially *Anopheles,* most important is the aquatic vegetation usually so abundant about the edges of ponds and streams. No matter how large and deep the pond or how swift the stream, such a body of water is dangerous if it has low, weedy banks. No larvæ can live even in a comparatively slow current or in any pond with clean margins and large enough for the wind to raise wavelets, but if vegetation causes "dead water" in a stream or pond the larvæ are protected from wind, waves, currents and often from small fishes that prey upon them. Furthermore, the little bays and segregated pools of all ponds and streams with marshy banks are likely to be prolific breeding places. The particular kind of vegatation seems to make little difference, so long as it does not cut off all sunlight. Vegetation almost or even entirely submerged, like the common water-weed (*Elodia canadensis*), or with floating or slightly-emersed foliage, like pond-lilies and water-cress, or almost wholly above water, like grasses and sedges of moderate height, are alike favorable.

The season's field work has amply borne out these general statements. The banks of the east branch of the Rahway river at Maplewood and at South Orange, where it is a tolerably swift stream, are weedy in places and have little bays and lagoons. All these places harbor larvæ, especially those of *Anopheles.* In Branch Brook park, Newark, no larvæ were found in the large ponds, which have clean, well-kept shores, are free from vegetation and are exposed to the full sweep of the wind; but in the lily ponds, where not only "lilies" (*Nympheaceæ*), but arrow-leaf (*Sagittaria*) and grasses abound, there were numerous larvæ, notwithstanding these ponds are stocked with gold-fish. The grassy borders of the Morris canal are another prolific breeding place. It is well known that this canal extends for many miles through Northern New Jersey. Since it is now fallen into disuse, its banks have grown up to weeds and water plants; thus, it has become a menace to the health of the communities through which it passes.

The rather numerous bodies of standing water in Harrison have not yielded many larvæ, except in very restricted localities. This is due to (1) natural enemies, (2) lemna, (3) tall reeds and cat-tails and (4) the clean margins of most of the ponds.

The extensive flooded area between Fourth street and the Passaic river, bounded north and south by two branches of the Pennsylvania railroad, is stocked with small fishes, abounds with water bugs (especially *Notonecta*) and is partially covered with lemna or duckweed. No larvæ were obtained here. Similar conditions obtain in the flooded meadow between Manor avenue and the Gilbert estate, with the addition of cat-tails and reeds all about the flooded area. In the great meadows to the east and south of Harrison the very dense growth of cat-tails (*Typha augustifolia*) and "reed grass" (*Phragmites communis*), both overtopping a man's head, prevents access of sunshine to the surface water, so it remains cold during the hottest weather. These vast tracts along the lower course of the Hackensack and Passaic rivers are, therefore, not everywhere productive of vast swarms of mosquitoes, as they are popularly supposed to be. It is only in certain localities where the sun has access that they afford prolific breeding places. Such localities are to be found here and there around their borders and in areas where the tall growth has been cut.

In the eastern part of Harrison are several small "kettle hole" ponds and one pond of several acres in extent known as Fairy lake. With the exception of a shallow, temporary pool, densely overgrown with button bushes and very muddy, none of these ponds are favorable breeding places, and in some of them not a single larva was obtained. As to Fairy lake, it seemed to support no animal life whatever. I was informed that so much acid had been discharged into the lake by a neighboring brass work factory as to kill all the fishes. The pond has remarkably clean, gravelly shores and contains little or no vegetation, with the exception of a few spatterdocks (*Nuphar advena*) at one end. Some of the water was brought to the laboratory and *Culex* larvæ placed in it. They lived in it indefinitely; and I am therefore inclined to think that the clean margins and unobstructed surface of the pond have more to do with keeping it free from larvæ than the acid. There are two or three very similar but smaller and uncontaminated ponds in the immediate vicinity, occupying depressions in the glacial drift like the well-known "kettle holes" of Cape Cod and Long Island. These ponds have clean margins, no vegetation, except th spatterdocks (present in only one), are stocked with small fishes and remain destitute of mosquito larvæ throughout the season.

Conditions most favorable for the breeding of *Culex pungens* are afforded by uncovered cisterns, rain-water barrels and barnyard pools. Such are, fortunately, not numerous in Harrison and Kearny; but two of the sewers discharging to the eastward, into open ditches in the meadows, afford ideal conditions for the breeding of this species. Not that the larvæ occur in the sewer itself or in the ditches—the current is too rapid. Exceptionally high tides back flow the sewage and cause it to overflow the banks of the ditches, where they are too low, and the standing water thus created swarms with the larvæ of *Culex pungens.*

Anopheles was found breeding in abundance in only one place—the ditch in the railway cut of the Erie road, North Arlington. A fine spring furnishes much of the water, the rest of which trickles from the rocky walls. The ditch lacks sufficient fall to carry off the water, and for a long stretch it is chocked with grasses, watercress and *Cyanophyceæ* or blue-green algæ. This latter vegetation evolves so much oxygen it is floated at the surface by the bubbles, and thus furnishes both food and shelter for the surface-dwelling larvæ. These conditions—stagnant ground water, warmed by the sun, abounding in minute algæ and larger vegetation and free of fishes and most insect enemies—are perfect for the breeding of *Anopheles,* which does not appear to thrive in the foul water so favorable for *Culex pungens.* As a matter of fact, *Anopheles* larvæ may occur in waters habitable for any kind of mosquito larvæ; but, so far as the experience of the past season has shown, they are plentiful only in places where such conditions as those above described are fulfilled.

Other breeding localities for *Anopheles* were: (1) Small muck-holes near Manor avenue, Harrison (these dried up about August 1st); (2) flooded grounds on both sides of Manor avenue; (3) pool near Schuyler avenue, Arlington (only in September); (4) weedy margins of Verona lake, also its inlet and outlet; (5) ditch in eastern part of Verona; (6) tributary of east branch of Rahway river at Maplewood.

Natural Checks to the Breeding of Mosquitoes.

These are of two sorts—animal and vegetal. Among the latter is emna or duckweed. While most forms of aquatic vegetation promote he breeding of mosquitoes, the *Lemnaceæ,* or duckweeds, are unfavorable, and in many waters almost or even wholly prevent it. These tiny plants consist merely of a floating frond, resembling a miniature lily pad. It is circular or more frequently lobated and three to six millimeters in diameter. From the under surface hang one or more roots, which never fasten in the soil, but derive their nourishment from the water. Its reproduction, mainly by division of the frond, is so rapid that in a short time (usually before July 1st) it completely mantles quiet waters, notably sheltered ponds and ditches, without perceptible flow. Its extraordinary abundance, often covering whole acres of shallow water, makes it an efficient protection from mosquito breeding. Wherever this plant forms a complete covering no larvæ have been found. Such places should never be treated with oil, for nature has provided a far more lasting and equally effective protection. It is probably impossible for a mosquito to lay her eggs on lemna-covered water. Even should larvæ wander in from adjacent waters, they would be unable to reach the surface for air, and would thus soon become asphyxiated. Larvæ of *Culex pungens*, injected by means of a pipette beneath the lemna in the jar shown in Figure 10, died in less than an hour. Where the lemna mantle is not complete, but presents interspaces of open water, larvæ of both *Culex and Anopheles* will usually be found in small numbers only, for lemna waters are apt to harbor the various predaceous water bugs in great numbers.

Insect Enemies.—Probably all the predatory water bugs and beetles, both in the adult and larval state, prey on mosquito larvæ. These carnivorous insects abound in shallow, permanent bodies of water wherever there is vegetation. It is not surprising, therefore, tha such waters should produce far fewer mosquitoes than temporary pools where enemies are absent. Among these predatory insects the water boatmen (*Corisa* and *Notonecta*), the water striders or "skate bugs" (*Hydrobatidæ*) and the water scorpions (*Nepidæ, Belostomatidæ* deserve mention. My observations were mainly confined to the "wate tiger" or larva of the large water bettle (*Dytiscus*). The ability of thi voracious creature to clear a pool of larvæ was demonstrated in th laboratory by several captive water tigers, all of them young ones about a centimeter in length, which created havoc in some of the jar containing *Culex* larvæ.

An outdoor demonstration was afforded by a small pool about hal a mile south of the North Arlington railway station, between Schuyle avenue and the meadows. To all appearances this pool, which wa barely ten feet across in July and gradually diminished during th

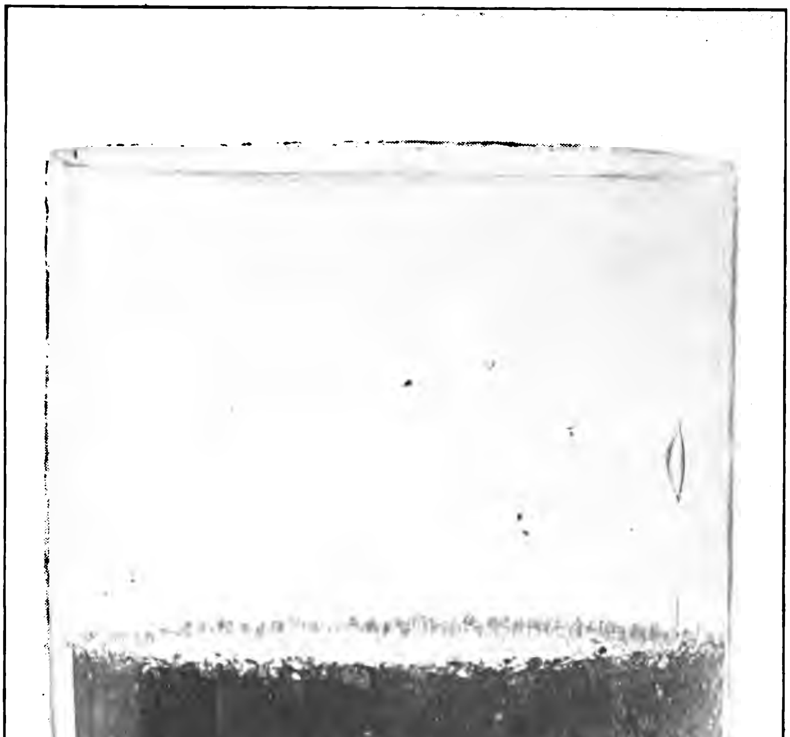

Fig. 10.

A jar of water covered with Duck Weed, showing how the roots extend into the water and bar all access to the surface. From an original photograph.

summer, possessed every condition for the breeding of mosquitoes in great numbers. It contained no fish and few water insects, with the exception of the *Dytiscus* larvæ, which seemed quite abundant. On July 26th, when first visited, the pool was thoroughly examined, but yielded very few larvæ of *Culex* and only two or three of *Anopheles.* The pool was visited again early in August, but no larvæ were found; again August 18th, when a very few *Culex* larvæ were obtained. In order to determine whether the water was incapable of supporting larvæ, ten large and medium-sized *Anopheles* larvæ were placed in a sample of it brought to the laboratory. The next morning there were only eight. The loss of two was accounted for by the presence of a very small water tiger, which had been accidentally left in the jar, and at the moment of discovery had a larva in his jaws. After removal of the enemy, seven of the larvæ completed their development, and all had pupated by the 25th, thus proving that the water was by no means unsuitable for the development of *Anopheles.* The pool was visited again September 6th. Both *Culex* and *Anopheles* larvæ were found in fair abundance, but no *Dytiscus* larvæ were seen. The absence of the voracious water tigers, owing, presumably, to metamorphosis, seems the most plausible explanation of the great increase in the number of mosquitoe larvæ.

Breeding Habits and Development.

I shall confine this division of the subject to a few personal observations. What I have learned this summer is almost entirely limited to *Culex pungens* and *Anopheles punctipennis.* The data have been gathered during only about two months (July 15th to September 15th), and are, consequently, almost wholly in the laboratory, fragmentary and incomplete.

Egg-laying.—Many observers have had, apparently, no difficulty in getting mosquitoes to lay in confinement, but such has not been my experience. In no single instance have they done so, although liberally supplied with water and given every opportunity. Hence, I have no observations to record concerning the laying or the eggs of *Anopheles,* which are hardly to be found in the breeding pools, as they do not cohere to form an egg-boat, but scatter singly over the surface, and thus generally escape detection.

The number of eggs deposited by *Culex pungens* on a limited quantity of water during a season is roughly arrived at by removing the egg-boats every morning (they are laid only at night or in the early morning), and keeping a record of them. About July 10th an ordinary, wooden waterbucket was placed in a basement window of the Harrison Board of Health office, where mosquitoes had easy access to it through a grating. It was examined every day for a week or so, but no eggs were found; the most probable explanation being that the bucket was new and the water too clean to tempt *Culex* to lay. On August 2d, after an absence of a week on account of illness, and subsequent remissness in examining the water, I found a brood of *Culex pungens* larvæ, about three-quarters-grown, also an egg-boat. The larvæ were all about the same size, and evidently came from a single laying. Some of them were allowed to remain and pupate. The pupæ were all removed August 7th and hatched August 9th.

Eggs were taken at the following dates:

Aug. 2	1	egg-boat.
“ 4	5	“
“ 5	2	“
“ 6	1	“

An iridescent scum appeared on water, and no more eggs were laid until water was changed.

Aug. 14	5	egg-boats. Bucket placed in yard.
“ 15	3	“

Bucket accidentally upset and water renewed.

Aug. 22	1	egg-boat.
“ 31	1	“
Sept. 7	1	“
“ 12	1	“
Total	21	egg-boats.

Adding one laying from which the well-grown brood of August 2d had hatched, gives a total of twenty-two. The nights after September 12th were cold, and no further laying had occurred up to September 17th, when observation ceased.

The weather affects egg-laying. The careful observations of Kerschbaumer (1901, p. 86) are very conclusive on this point. On cold, windy nights few mosquitoes lay their eggs; nor do they lay on rainy nights. Although the record was much interrupted by twice renewing the water, the number of eggs laid on this small quantity of water between July 15th and September 12th, at the very conservative estimate of 150 eggs per laying, amounts to 3,300 eggs. The chances are that the great majority would have developed to the perfect insect, for food was abundant and enemies none. If 3,000 developed to the perfect insect, then about half, or 1,500, would have been females. These figures are respectfully submitted to the consideration of those who have standing water on their premises.

So far as my observation goes, the eggs of *Culex pungens* almost invariably hatch the night or early morning following that on which they were laid. Howard (1900, p. 23) mentions sixteen hours as the minimum time from egg-laying to hatching. I have noted only one exception to the usual period under ordinary conditions of temperature, and then the eggs hatched on the second morning. It is only necessary, however, to reduce the temperature to delay hatching. A bunch of eggs, found the morning of September 7th, was placed in an ice-chest at 9° C. (48° F.) at 12:30 P. M. the same day, and left there until 4 P. M. the next day. Then they were kept at room temperature, which varied from 20° to 25° C. (68° to 77° F.). They hatched on the morning of September 10th, about seventy-two hours after the time of laying.

Larvæ of Culex pungens.—The newly-hatched larvæ are about one millimeter in length, very transparent, active and have disproportionately large heads. The heart beat is plainly visible. I have timed it when the temperature was 27° C. (84.5° F.) and found it to vary even in the same larva, but to average ninety-four beats per minute.* The observation was made in the region of the thorax.

Kerschbaumer (1901) distinguishes four stages of larval growth: (1) Young larvæ, in which the thorax is still no larger than the head; (2) small larvæ, with thorax somewhat larger than the head; (3) half-grown larvæ, and (4) full-grown larvæ. A molt intervenes between each of these stages. The molt is fragmentary and inconspicuous; no larval "skins" are found in the water until the final molt, when the pupa emerges. At this time the larval skin splits open on the dorsal side of the thorax, and the two breathing tubes of the pupa are thrust out first. At this time the caudal breathing tube of the larva is still apparently in use. With a flop the pupa fairly "jumps out of its skin," and the latter floats away, the breathing tube still adhering to the surface of the water.

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*Average of five counts.

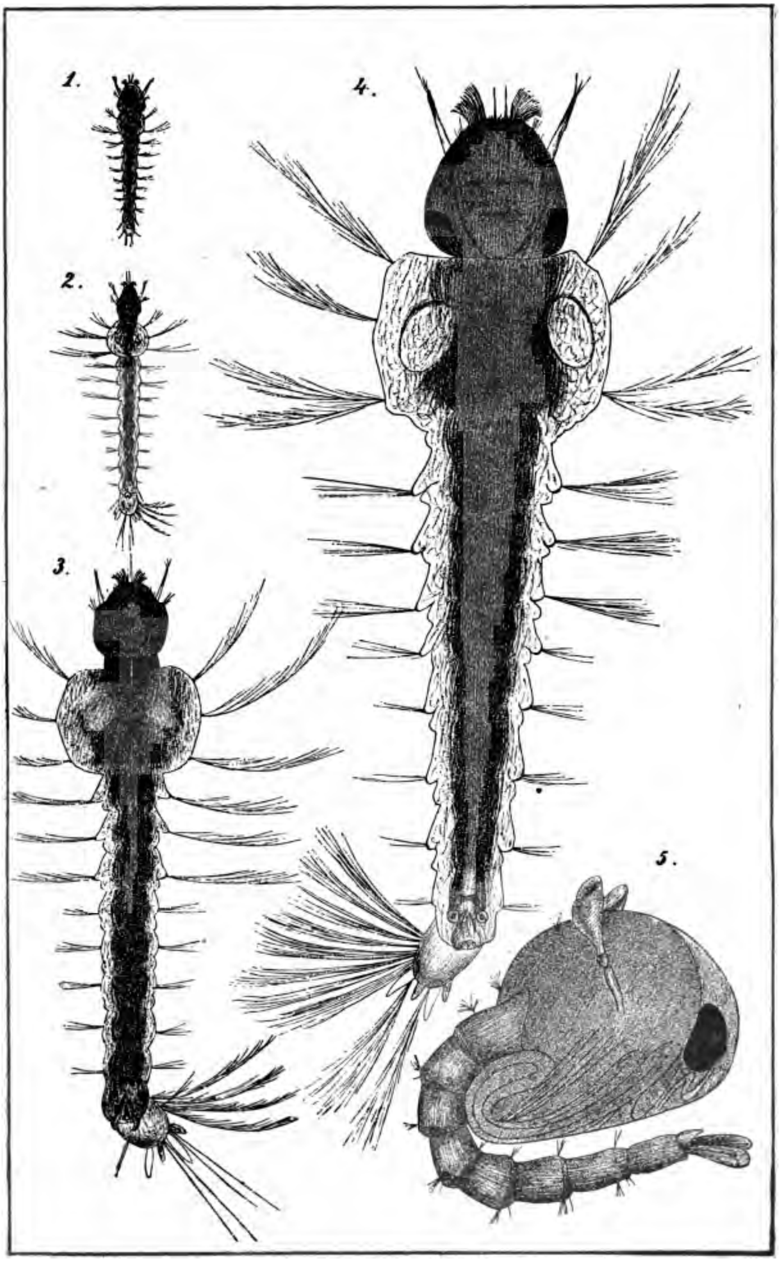

Fig. 12.
Larvæ of *Anopheles maculipennis:* 1, young larva; 2, small larva; 3, half-grown larva; 4, full-grown larva; 5, pupa: enlarged. After Kerschbaumer.

Duration of Larval Life.

This depends upon the conditions of larval existence. The very short period of one week has been reported by Howard (1900, p. 26), but this is possible only in the hottest summer weather and with superabundant nourishment. A fair average, under ordinary conditions, would be about two weeks. Larvæ of *Culex pungens,* reared from the egg in the laboratory and insufficiently nourished during the greater part of their existence, pupated at the end of seventeen days to three weeks, and then at a stage of growth indicated as a half-grown larva in Figure 12. The little pupæ (13 *c*) naturally produced dwarfish adults, and there were twice as many males as females.

The very slow growth of *Anopheles* larvæ under laboratory conditions has been a serious hindrance in rearing them. Usually only the full-grown and nearly full-grown larvæ brought to the laboratory lived to pupate. One-third to one-half-grown larvæ (three to four millimeters long) can be carried through only by constant care. In order to obtain adults in large numbers, it is, therefore, necessary to collect as many advanced larvæ and pupæ as possible.

Duration of Adult Life.

It is often asked, "How long does a mosquito live?"—a question to which a satisfactory answer cannot be given. We know they may and do live a long time under certain conditions. For instance, hibernating mosquitoes live through the winter—even the long Arctic winter. In the tropics they live through the dry season, when breeding is impossible. In captivity they have been known, exceptionally, to live two months; but mosquitoes in confinement are not under normal conditions. It is possible that our summer mosquitoes live longer than the usual lease of life of our captives, which I have found not much to exceed one month for *Culex pungens* and *Anopheles punctipennis.* On the other hand, the usual free life may be briefer. As already stated, my captive mosquitoes have never laid their eggs. It is quite probable the females are not impregnated in captivity, although I have constantly kept males and females together. When an insect has laid its eggs its mission is ended, and it soon dies. If anything prevents or defers egg-laying, then the female may live on. If the males, for any reason, fail to perform their function, they, also, may greatly exceed their usual term of life.

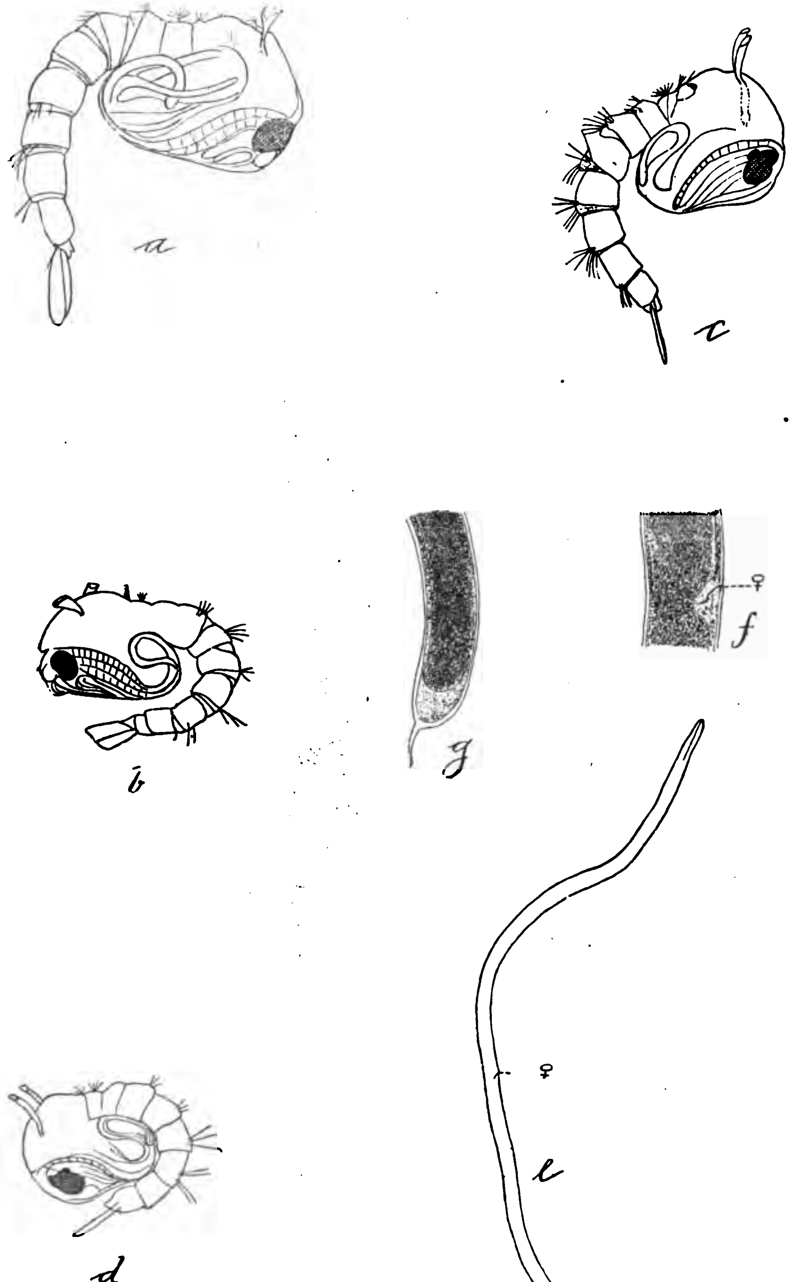

Fig. 13.

All mosquitoes upon which I have based longevity observations have been reared from the larva or pupa. They have been kept in cylindrical, gallon, battery jars. The mouth of the jar is closed with mosquito-bar, held in place by a rubber band. The jar is always kept supplied with water, sometimes also with earth, in which grass or other plants are rooted (although this plan was found objectionable, and was discontinued), and usually with two or three sprigs of "wandering jew" (*Tradescantia*). Ripe fruit, particularly bananas and pears, was used as food, and the female *Anopheles* were allowed to bite at intervals of three or four days. Under these conditions *Culex pungens* have been kept for forty days and *Anopheles punctipennis* for about a month, when the experiment had to be brought to a close. Only a few out of a considerable number have lived so long. The objection may be raised that mosquitoes born so late in the season (August 9th to 19th) may belong to a hibernation brood, which would account alike for their comparatively long life in captivity, and also for their failure to lay eggs. This, however, was not the case, for all, both males and females, fed freely on the fruit, and the female *Anopheles* bit eagerly, even after the middle of September. No conclusions could be drawn from the failure of the later broods of *Culex pungens* to bite, because they had refused to do so throughout the season. Furthermore, a considerable number of females were dissected, and were found to have fully-developed eggs in their ovaries.

Examination of considerable numbers of *Culex* and *Anopheles* from the Boston Parental School, during October and November, 1901, revealed only empty stomachs and undeveloped ovaries. These mosquitoes were all captured indoors, most of them in sleeping-rooms, where they had had every opportunity to bite. It is evident that they had not come indoors to get a meal of blood, but to find hibernation quarters. They were, therefore, the "hibernation brood," which is always the last brood of the season.

The long lease of life of some of the males was a surprise, in view of the reiterated statements of writers to the effect that the males are short lived. A few records are given.

Explanation of Fig. 13.

a, large pupa of *Anopheles punctipennis*, about the maximum size; *b*, very small pupa of same from an undersized larva; both enlarged 9 diameters; *c*, unusually large pupa of *Culex pungens*; *d*, same from an undersized larva reared in the laboratory; both show the small black larval eye adjacent to the large compound eye, and are enlarged 9 diameters. All the above form camera lucida drawings; *e*, thread worm, parasitic in body cavity of *Anopheles* larva from Delair; ♀ enlarged 12.5 times; *f*, vaginal region of ♀, enlarged 63 times; *g*, caudal extremity of same, enlarged 63 times; in figures *f* and *g* the small round bodies are ova. Original by H. P. Johnson.

Culex pungens.—Pupæ from waterbucket in basement. August 7th, pupæ put in battery-jar, provided with earth, water and living plants:

Aug.	16	4 males, living.
"	26	3 " "
"	28	2 " "
Sept.	2	1 male, 8 females.
"	5	1 "
"	6	No "
"	18	5 females, which were cholroformed, and record closed.

Longest life of a male, twenty-seven days; of females, forty –|– days. August 9th is taken as date of hatching from the pupa.

Psorophora ciliata.—Received as larvæ from Mr. William P. Seal, Delair. Pupæ put in battery-jar, arranged as for *Culex pungens.*

Aug.	2. (9:30 A. M.)	1 male, just emerging from pupa.
"	4	2 males, 2 females.
"	13	1 male (dying), 2 females.
"	17	2 females.
"	19	1 female.
"	20	Extinct.

Longest life of a male, nine days; longest life of a female, sixteen days.

Anopheles punctipennis.—(First colony).

Aug.	8.	Started with 19 pupæ.
"	9.	(12 M.) 1 female, 5 males.
"	9.	(6 P. M.) 1 female, 7 males.
"	11.	(10:40 A. M.) 4 females, 7 males.
"	12.	Two dead males found.
"	14.	4 females and 5 or 6 males still alive.
"	14.	12 pupæ added. Two hatched to-day.
"	22.	Males dying off.
"	25.	3 or 4 males left.
"	25.	3 pupæ added.
"	27.	2 pupæ added.
Sept.	3.	3 females, 2 males (from pupæ added August 25th and 27th).

(Record closed.)

Anopheles punctipennis.—(Second colony).

Aug	13.	Many pupæ placed in battery-jar.
"	17.	12 pupæ placed in same battery-jar.
"	18.	12 pupæ still unhatched.
"	19.	3 pupæ still unhatched.
"	23.	Several males still alive.
Sept.	2	5 males, 8 females.
"	4.	5 " 8 "
"	8.	3 " 8 "
"	10.	3 " 5 "
"	12.	3 " 4 "
"	13.	3 " 3 "
"	15.	3 " 3 "
"	17.	3 " 2 "

(Record closed.)

The last record is the most remarkable, for the males actually held their own better than the females. The conditions for both sexes were precisely the same, except that the females were allowed to bite at intervals, which the males always refused to do.

Proportion of the Sexes, Apparently Determined by Degrees of Larval Development.

With *Anopheles* it was a matter of practical importance to separate the large pupæ (13 *a*) from the small ones (13 *b*). In order to obtain a stock of large, vigorous females for inoculation experiments, it was necessary to get large pupæ from which to rear them. Most of these were pupæ collected out-of-doors or pupæ from very large, full-grown larvæ recently brought in. Of course, large size presupposes ample food, abundant sunshine and possibly other favorable conditions not always realized indoors. Pupæ coming from larvæ that had been long in the laboratory were generally small.

Both from the scientific and the practical point of view much interest inheres in the determination of sex by the external conditions of life. Nowhere have experiments more clearly shown that the proportion of the sexes may be controlled than among insects. Mrs. Mary Treat, of Vineland, N. J., has recently published (1898) an account of a most interesting series of experiments with the butterfly (*Papilio asterias*). When the caterpillars were underfed a great preponderance of males was obtained, almost, but never entirely, to the exclusion of females. Landois obtained in the same way similar results with the caterpillars of *Vanessa urticæ.*

My results with mosquitoes, while too scanty to be conclusive, are, perhaps, worth recording.

Twenty-three large pupæ of *A. punctipennis* gave fifteen females and six males. Two pupæ died. Therefore, 71.43 per cent. were females and 28.57 per cent. were males. Twenty-three small pupæ of *A. punctipennis* yielded three females (20 per cent.) and twelve males (80 per cent.); eight died either as pupæ or in the act of hatching. There is often a high rate of mortality among the small pupæ.

A single experiment was made with *Culex pungens.* Larvæ hatched from the egg on August 4th, and 5th were kept in a dish in the laboratory, without sufficient food, and the first pupa was found August 23d, which must have come from a larva not more than half-grown. Four more pupæ appeared two days later; and, to stimulate pupation, the larvæ were now liberally fed. By the 29th about twenty pupæ had appeared; these had all been placed in a battery-jar, and yielded twelve males (66 2-3 per cent.) and six females (33 1-3 per cent.).

Food of Larvæ.

A good many experiments were made to determine the best food for rearing the larvæ of *Anopheles,* and, incidentally, a few with *Culex pungens.* The conclusion reached from these experiments and from microscopic examination of the contents of the alimentary canals of the larvæ was that the minutest algæ, notably *Protococcus, Scenedesmus, Raphidium, Cosmarium,*[*] and no doubt a variety of other Desmids and Diatoms, form the chief food of the larvæ. Bits of filamentous algæ (Spirogyra, etc.) are also swallowed; but animal food was not detected. The larvæ browse on decaying vegetation, eating off not only minute vegetal growths (Bacteria, etc.) that cover it, but the cellular substance of the leaves and stems as well. Epidermal cells of leaves have been found in the stomachs of larvæ.

A good way to promote the growth of *Culex pungens* larvæ is to put grass in the water. In decaying it promotes the development of bacteria, and, later, of microscopic algæ. It is evident, from the prompt growth of the larvæ, that the rotting grass, stems and leaves, and possibly the bacteria, serve as food. As already noted, larvæ of

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[*] **I am indebted to Mr. Horatio N. Parker for the determination of these.**

C. pungens thrive in very foul water, even that contaminated by sewage. *Anopheles* larvæ I have never found in such water.

The fact that the great bulk of the contents of the stomachs of both *Anopheles* and *Culex* larvæ is *Protococcus,* indicates this as a staple article of diet. I have not observed much selection of the particles brought to the mouth by the vortex created by the maxillary brushes, and there is nothing to indicate such selection in the contents of the stomach. *Anopheles,* being largely a surface-feeder, draws to its mouth all sorts of floating particles. On dusty days a great deal of inorganic matter falls on the water, and these wholly innutritious particles find their way to the stomach in sufficient numbers to make its contents decidedly "gritty." The view expressed by Howard (1900, p. 38), that the specific gravity of the *Anopheles* larva is materially reduced because it feeds upon floating particles, and therefore "it supports this horizontal position just beneath the surface film with comparative ease, and, in fact, without effort, the tension of the surface film itself being hardly needed to hold it," is not sustained by this observation. The large amount of mineral matter which the *Anopheles* larva occasionally takes in certainly does tend to increase its specific gravity, and yet it remains at the surface without the least effort. I have frequently seen the larvæ feeding at the bottom, and lying there inert, without the slightest visible movement or apparent effort. It is evident, then, that their specific gravity, like that of most animals, is actually greater than that of water, and they remain at the surface in a horizontal position because held there by surface tension. Not merely the cephalic and caudal extremities, as represented by Howard (1900, Figure 14; 1901, Figure 19), break the surface film, but, as a rule, the entire length. The position shown by Howard, with only head and caudal end breaking the surface, is sometimes assumed, but it not usual or typical.

Biting Habits.

These particular "habits" of mosquitoes may be considered to require no remark. Most people would regard them as well known already. Still, there are misconceptions regarding this pernicious practice of the female mosquito.

Males, apparently, never bite. Not that they are averse to blood, for Berkeley (1902, p. 29) has found that they will feed upon it if it is offered to them on a swab. Many times I have tried to induce male *Anopheles* in confinement to bite, but have never succeeded. Female *Anopheles,* a certain number of days after coming from the pupæ, bite quite freely, even during the daytime, which is contrary to their habits when free. In no instance have I been able to induce *Anopheles* to bite until at least six days after leaving the pupa. During this interval, however, they frequently suck the juice of ripe fruit.

It is commonly believed that a mosquito that has gorged itself will not bite again; but recent experimental studies have exploded this idea. Indeed, the transmission of both malaria and yellow fever depends on their biting at least twice. I find that *Anopheles* that have bit once are, if anything, more likely to bite again. They even bite sometimes as frequently as every other day, when they have not fully digested the previous meal. A female *punctipennis* that was kept isolated bit at 9:30 A. M. September 3d; at 10:50 A. M. September 6th; at 11 A. M. September 8th, and at 10:30 A. M. September 10th. After that she was evidently satisfied, for I could not induce her to bite again.

Why female mosquitoes bite is not certainly known. It is sometimes thought that they need the blood in order to mature their eggs; but it has never been satisfactorily shown that they cannot lay after partaking of a simple diet of the juices of plants. Wherever they swarm in uninhabited regions this must be the case. The fact that both *Anopheles* and *Culex* of the hibernation brood do not partake of blood in the autumn before going into winter quarters (when their ova are to remain undeveloped for months), but are most bloodthirsty after they emerge in spring (*Anopheles* at this time, as I have observed, biting even in the daytime), seemingly indicates a correlation between a meal of blood and the rapid maturing of the eggs.

Parasites.

Beautiful clusters of Vorticellids are frequently to be seen on the thorax, abdomen, and even on the head of the larvæ of *Culex pungens.* They may be so abundant as to give the thorax, especially, a whitish, gelatinous appearance to the naked eye. It is unlikely that these Vorticellids do the larva any harm, as the larva simply affords them an attachment and transportation—possibly, food also—brought by the vortex which it creates in the water.

The only internal parasite found was a small Nematode, or thread-worm (Figure 13 *e*), in the larvæ of *Anopheles*. It lives in the body cavity, and is probably not very common. Six were obtained during the summer, all from larvæ sent to me by Mr. William P. Seal, of Delair. Only one was found by dissection, the others were in the bottom of a dish containing a newly-received lot of the larvæ, many of which were dead. The Nematodes were alive, however, and had very likely crawled out of the dead and partly-disintegrated larvæ. The Nematode is about twice as long, on the average, as the larva it inhabits, the specimens represented in Figure 13 *e* measuring 9.17 mm. in length and .16 mm. in greatest diameter, tapering slightly towards anterior and posterior ends. The opening of the vagina (Figure 13 *f*, female) is slightly nearer the head than the posterior extremity. The anus has not been found. The caudal extremity (Figure 13 *g*) is filiform, and tapers to a fine point; its length is not quite equal to the diameter of the posterior region. The entire worm, except a limited region at the posterior extremity, is packed with very minute ova, which completely conceal the intestine. No oral papillæ have been detected.

More abundant material and other stages in its development are necessary to determine the relationships of this interesting parasite. It is possible that it is sometimes numerous enough and sufficiently injurious to serve as a check on the increase of *Anopheles*.

The Transmission of Malaria.

There is a wide-spread misapprehension regarding the way in which malaria is transmitted by mosquitoes. Many who unhesitatingly accept this view are unable to explain upon what foundation it rests, or why it has so quickly won the acceptance of biologists the world over. Many, even of the medical profession, attach little or no importance to the really great differences in the modes of existence of the various disease germs. Hence, it is not surprising that they should regard the malarial organism as a germ of the same sort as bacteria, endowed with the well-known power of most bacteria to live outside the animal body and withstand cold, heat, dryness and other adverse conditions. If this were so, modes of transmission other than that by mosquitoes would require the most careful consideration. No reputable pathologist or bacteriologist would venture to assert that one might not contract malaria as one contracts typhoid or diphtheria or small-pox. The simpler the life history of a pathogenic organism, the greater the variety of conditions under which it can lead an active existence. As compared with bacteria, the life history of the malarial organism is exceedingly complex; accordingly, we find its conditions of existence rigorously restricted. So far as known, not one of the whole great group of the Sporozoa (literally, spore-producing animals), to which the malaria organism belongs, can lead an active existence outside its appropriate host. Without exception, they are obligatory parasites. Probably all of them pass at least a portion of their cycle within the very cells of their host. It is not surprising, therefore, that none of the Sporozoa have been found to lead a saprophytic existence; that not one has been cultivated outside its host. With the bacteria, on the contrary, it is the exception that they cannot be reared on nutrient media.

The host species of any Sporozoon are always few and closely related; frequently there is but one. Again, within the body of the host these fastidious parasites elect only cells of a certain tissue, and often even that tissue as it occurs in some particular organ. Thus, the entire order Hæmatozoa, to which the malarial organism belongs, live in the red blood corpuscles, but in no other part of the vertebrate body. Here they are completely shut in from the outer world, to which they have no direct access. The blood-sucking habit of the mosquito affords them an exit—first, to the mosquito's body, where they pass through a cycle different from that in the blood, and then, by the agency of the mosquito, back to the circulation of man, beast or bird, according to the special form of malaria.

The Hæmatozoa differ from the rest of the Sporozoa, inasmuch as they live in two hosts, vertebrate and mosquito or some other blood-sucking parasite. In all forms of human malaria yet investigated the carrier host is a mosquito of the genus *Anopheles*. This reveals the highly-specialized nature of their parasitism. *Culex,* so nearly related to *Anopheles,* so like it in all its structure, physiology and habits, cannot become infected, so far as known, with any form of human malaria. On the other hand, the malaria of birds, which differs slightly from human malaria, cannot be transmitted by *Anopheles*, but only by *Culex*. Yellow fever, again, has been experimentally shown to be transmitted by still a third form of mosquito, *Stegomyia fasciata*. For the germ of cattle fever (known in this country as Texas cattle fever) no species of mosquito, nor even any true insect, serves as the transmitting host, but a blood-sucking parasite of the Arachnid group, the cattle-tick (*Boophilus bovis*) (Smith and Kilborne, 1893). Indeed, there is strong circumstantial evidence that a rare and local human hæmatozoic disease, the "spotted fever" of the Rocky Mountain region, is transmitted by the bite of a tick (Wilson and Chowning, 1902).

Can any species of Sporozoon pass from host to host without an animal carrier? The answer to this question concerns us much. As soon as it is demonstrated that even one form of the disease-producing Sporozoan can pass from one vertebrate to another, we naturally inquire whether this may not be the case sometimes with the malarial parasite also. The answer is, emphatically, no! Notwithstanding there are numerous Sporozoa which pass from one host to enter another of the same species, with an intermediate sojourn in the outer world, this passage is made in the form of encysted spores. Encystment is absolutely necessary to protect these delicate organisms from dessiccation. Since no encystment occurs with the malaria germ, or with any of the known Hæmatozoa, we are justified in concluding that direct transmission is impossible for them. Like the seed of a plant, the animal spore must reach a suitable soil before it can germinate. The only suitable soil is the body of its appropriate host. To give a specific instance: There is a disease of rabbits known as Coccidiosis, caused by the Sporozoon *Coccidium oviforme,* which invades, in vast numbers, the epithelial cells of the gall ducts and small intestine. *Coccidium oviforme* has a life history almost identical with that of the malarial parasite, but with the important difference that both the sexual and asexual cycle are passed in the same host. The rabbit is, so to speak, both the intermediate and the definitive host,* and the Coccidium has simply to pass from rabbit to rabbit. This it does in the most direct way possible, passing out of the body in the form of spores with the fœces, and then, still in the spore form, is taken with the food into the digestive tract of another rabbit, which it infects in turn. Were such a simple mode of direct infection possible for the malarial parasite, we may be well assured it would be followed; for nature does not adopt roundabout methods when direct ones will serve her ends. To the parasitologist, therefore, the fact that experiments have shown beyond a doubt that malaria is transmitted by mosquitoes is sufficient proof that this is the only means of transmission.

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* The use of the terms 'intermediate" and "definitive" as applied to hosts has heretofore been accurate and clear to parasitology, but unfortunately the mosquito-malaria-theory has introduced some confusion. The definitive host is invariably the one in which the parasite attains sexual maturity, and in which sexual reproduction occurs. All reproductive processes in the intermediate host are asexual. Hence man, not the mosquito, is the intermediate host of the malaria parasite, for the sporulation in the blood is asexual, while the phases in the mosquito are sexual.

We may, accordingly, dismiss once and for all the time-honored but never-proven doctrine that malaria germs lurk in damp soil or float in the miasma of swamps, ready to infect mankind whenever the soil is disturbed or the swamp air is breathed. That we may get malaria from swamps and in consequence of breaking the soil cannot be denied; however, we get it, not directly, but because these conditions favor the breeding of *Anopheles.*

Although the life history of the malarial parasite is a subject to which I can add nothing new, and one already much written about, it seems not superfluous, in view of the general failure to comprehend its true import, to state it quite fully, in language as untechnical as is consistent with accuracy.

At the outset it is necessary to define just what is meant by "malaria," for many and diverse ailments masquerade under this convenient guise. Many physicians diagnose as "malaria" a general malaise characterized by a slight fever, which is relieved by administering quinine. Again, there may be a "chill" as well as a fever. Even this does not prove a case of malaria, which can be diagnosed with certainty only from the blood. Unless, after reasonably diligent search, the malarial germ ("plasmodium" or "amœbula") is found in the blood, it is safe to conclude the disease is not true malaria, no matter what the symptoms. The malarial paroxysm or "chill" is undoubtedly the most reliable clinical symptom, but is not infallible.

If freshly-drawn malarious blood is kept at body temperature, and protected from the atmosphere, the plasmodia in the corpuscles may be seen to exhibit active streaming or amœboid movements; hence, the names "Plasmodium" and "Amœbula" are very appropriate. The plasmodium remains constantly within the corpuscle and feeds upon it. The hæmoglobin of the corpuscle is the source of the characteristic pigment seen in the plasmodium. Eventually the corpuscle is destroyed. The application of a suitable dye to a dried blood-smear on a glass slide or cover-glass, stains, not only the plasmodium in its entirety, but also its nucleus, thus demonstrating that the malarial organism is a cell. It is, in fact, a unicellular animal, a protozoon.

By far the commonest type of malaria in this latitude is the tertian, in which the paroxysm comes every other day. The quartan, in which the chill recurs at intervals of seventy-two hours, is comparatively rare; while the æstivo-autumnal, or tropical, fever with us is properly an exotic from the tropics or Southern Europe; but, according to Dr. Berkeley, it has obtained a foothold in New York City, where small epidemics of it occur every summer. In this type of malaria the chills come at irregular intervals.

Parasitologists now recognize that each of these three types of malaria is caused by a different and distinct species of malarial parasite, distinguishable by well-marked morphological characters. Thus, tertian fevers are produced by *Plasmodium vivax;* quartan by *Plasmodium malariæ,* and æstivo-autumnal by *Laverania malariæ.* Some have thought it possible to distinguish a fourth type, the quotidian, characterized by a daily paroxysm. The now generally-accepted explanation of this "type" is that it is simply the result of a double infection of tertian. It is possible, also, to have a double infection of quartan or of tertian and quartan, so that recurrence of the paroxysm may come sometimes every day, or even oftener, and, again, on alternate days.

In every form of malaria the chill marks an important epoch in the life history of the parasite. At this time "sporulation" is taking place—that is to say, the plasmodia, having attained the limit of their individual growth, and having used up all the nourishment afforded by the corpuscle, reproduce asexually. The nucleus divides into several daughter-nuclei, and each of these gathers to itself its due quota of the living substance, the protoplasm, of the mother-cell. The enclosing membrane of the used-up corpuscle now ruptures, and the spores (known technically as the "schizospores" or "merozoits") escape into the blood serum, and thence invade other corpuscles. In doing this they disturb the temperature equilibrium of the body, and the "chill" results. The giving of quinine is most effective at the onset of the chill, because, no doubt, the free spores in the blood are more exposed to the poisoning action of quinine than are the plasmodia in the corpuscles.

If the fever is left to take its course, more and more corpuscles are invaded and destroyed; the patient constantly gets worse. Whether a condition of effective resistance is attainable—in other words, whether we may at length become immune—is not known, because of the well-nigh universal use of quinine in all civilized countries, thus breaking up the fever before the body has time to develop any resistant powers it may possess. A fact of great significance in connection with this matter is the observation of Koch that the well-known immunity of the Negro race is not natural, but acquired. All Negro children in the malarious regions of Africa have malaria, and as they grow up gradually become immune. Natural immunity among Caucasians is extremely rare; but instances of it have been known in Italy.

The malarial organism was discovered in the human blood by the French army surgeon, Laveran, in 1880. Although his discovery obtained little acceptance for a decade, it has since become universally recognized as the cause of malaria, and has everywhere served as a valuable means of diagnosis. For years the presence of the plasmodium in the blood corpuscle was a standing enigma. It was not difficult to follow it through its apparently simple phases from the spore to the full-grown plasmodium, thence to the spore again. These changes take place with clock-like regularity. But how did the first germs get into the blood, and how can a parasite so located infect new individuals?

Light began to dawn on this knotty problem with the discovery, in 1897, by MacCallum, at Johns Hopkins University, of a new and entirely unexpected phase. Incredible as it may seem, these tiny organisms, unicellular though they are, have a sexual reproduction. The purely asexual, sporulating process in the blood may go on for a long period, but not indefinitely. Sooner or later some of the plasmodia assume an appearance different from the rest. The difference is but slight in tertian and quartan fevers, but in the æstivo-autumnal it is striking. In this form of malaria a large number of the plasmodia assume a semi-lumar form and are known as the "crescents." A general name now applied to these bodies is "gamete" or "gametocyte." On drawing a little blood and closely watching the gametes under the microscope the observation originally made by MacCallum may be repeated. Some of the gametes, distinguishable by slightly larger size, will suddenly be seen to give birth to several actively, lashing, thread-like bodies, known as the flagella or microgametes. These swim actively through the blood serum, and finally unite with other gametes, which have remained inert, producing no flagellated bodies. The union of these two bodies—the inert macrogamete and the tiny, active microgamete—constitutes the process of fecundation. It is essentially the union of the male element (spermatozoon) and the female element (egg or ovum), which everywhere inaugurates the development of a new being. Only, in the case of the malarial organism, we have to do with a unicellular parasite, and one perfectly adjusted to a very special mode of existence. It was soon ascertained that "exflagellation" (and, consequently, fertilization) never occurs until the blood has been drawn. The cycle which it inaugurates must, therefore, be passed somewhere outside the human body. But where and how?

Two years before MacCallum's discovery an English army surgeon stationed in India, Major Ronald Ross, following a suggestion of Manson, who had then recently discovered that human filariasis is transmitted by mosquitoes, began experimenting with mosquitoes of the genus *Culex*. The mosquitoes were allowed to bite persons suffering with malaria, but with uniformly negative results. The mosquitoes remained sterile. Finally, in 1897, Ross employed "dapple-winged mosquitoes" (*Anopheles*), allowing them to bite a patient whose blood contained the crescents of æstivo-autumnal fever. Four or five days later he found on the stomach of two of the mosquitoes pigmented bodies, evidently parasitic, which he rightly identified as the malarial organism. The matter, however, was not proved. It was not alone necessary that the patient should infect the mosquito; the mosquito, in turn, must infect a human subject. On account of the inevitable difficulties of experimenting with human beings, Ross employed birds, which have their own types of malaria, slightly different from human malaria. The mosquitoes used were of the genus *Culex*—the very species that had given only negative results with human malaria. The experiments were entirely successful. From biting malarious birds the mosquitoes became infected with the malaria. The germs could be followed in their development in the mosquito step by step until the cycle was completed. Then, multiplied ten thousand-fold, in the form of exceedingly minute sickle-shaped bodies (known as "blasts" or "sporozoits"), they gathered in the salivary glands, ready to enter, with the poisonous saliva, the blood of any bird that might be bitten. Healthy birds bitten by mosquitoes having the malaria germs in this stage of development in five to nine days were found to have the plasmodium in their blood.

While Ross was experimenting in India, a number of Italian investigators, prominent among whom were Grassi, Dionesi, Bignami and Bastianelli, had been busy with the same problem, and the results of their extended and painstaking researches showed, beyond a doubt, that *Anopheles* was the carrier and the intermediate host of the three best-known forms of human malaria, and that *Culex* played the same part for bird malaria. The "mosquito-malaria theory" was now no longer a thought, but an established fact. It only remained to work out details and conduct experiments of a less technical, but more comprehensible and more convenient, sort for those not versed in the intricate life histories of animal parasites.

What manner of development is it that takes place in the mosquito? The figures on Plate 14 (modified from Grassi, 101) will help to make it clear. Starting at 1 with the organism in the form of a sporozoit, which invades the human blood with the help of an infected *Anopheles*, we see, first, the simple, asexual cycle, which produces an attack of malaria. Each of the many sporozoits that *Anopheles* injects, with poison, into the blood seeks a red corpuscle and passes inside of it. It grows at the expense of the corpuscle, becoming the familiar plasmodium, and at full maturity divides into a small number of spores, which are scattered in the blood serum and promptly invade fresh corpuscles. Every time this occurs there is a "chill." At length, gametes appear, at first a few, then numerously. If the patient is now bitten by *Anopheles*, the fertilization (Figure 14, 6) takes place in the mosquito's stomach and the sexual cycle begins. As the first result we get a little, worm-like body, the ookinet or vermicule, which works its way into the wall of the mosquito's stomach. The stage shown in Figure 8 is passed in the wall of the stomach. The subsequent stages, characterized by very rapid growth, occur, apparently, on the outside (*i. e.*, the peritoneal surface) of the stomach, but, actually, just under the extremely thin, muscular and elastic layer, which is very distensible and stretches to accommodate the growth of the parasite. These large bodies soon become visible on the stomach of an infected mosquito (Figure 15,* four and one-half days after infection) with a low power of the microscope. Still, the growth continues (Figure 14, 11), and now we find there has been a division of the nucleus, and the more the amphiont (as it is called) increases in size, the more numerous become the nuclei. Each nucleus gathers to itself a stellate mass of protoplasm.

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* Dr. Berkeley's Figure 49.

Then, within this mass still further divisions of the nucleus take ace, the now minute daughter-nuclei crowding to the surface of the regular masses of protoplasm (Figure 14, 15). Each tiny nucleus soon the centre of a rod-shaped body, and there are several thou-nds of these rod-like bodies (the sporozoits) in the enormously-nlarged Amphiont. Large groups of them lie parallel to each other,

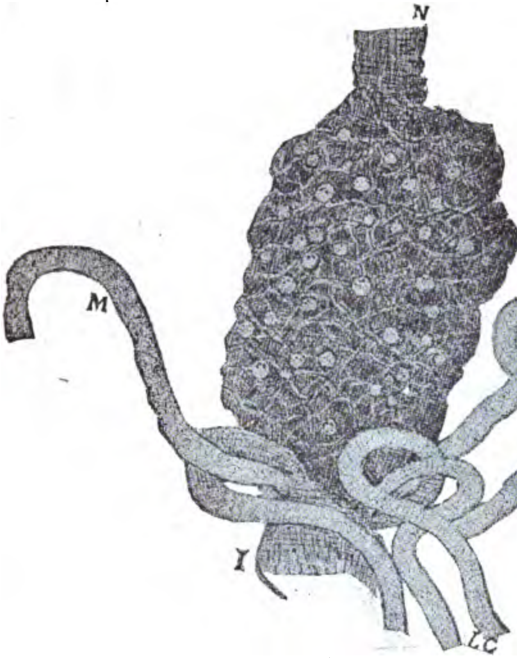

Fig. 15.

Stomach of *Anopheles maculipennis*, showing malarial Zygotes or Amphionts 4½ days old. The rounded, pygmented zygotes lie in the meshes of the muscular fibres. *N*, neck of stomach: *M* malpighian tubules; *I*, ileum. From Berkeley's Lab. Work with Mosquitoes.

producing the characteristic striated appearance (Figure 14, 17). The capsule bursts and the 10,000 or more sporozoits are set free in the mosquito's body cavity. Owing to some attraction of unknown nature, but presumably chemotaxis, they gather in the large, vacuolated cells of the salivary glands (Figure 16). Thence, they are injected, with the secretion, into the first person the *Anopheles* bites, and after a short period of incubation that individual comes down with malaria.

The same mosquito can, and no doubt often does, infect more than one indivudal. The length of time the sporozoits retain their vitality in the mosquito is not known. Observations by Grassi indicate that the sporozoits do not live through the winter in hibernating mosquitoes; and a study of mosquitoes by the writer (see page 575) in the autumn of 1901 would strongly indicate that hibernating *Anopheles* do not bite at all before going into winter quarters. But when they emerge in the early spring, such is their eagerness for blood, that they bite even in the daytime.

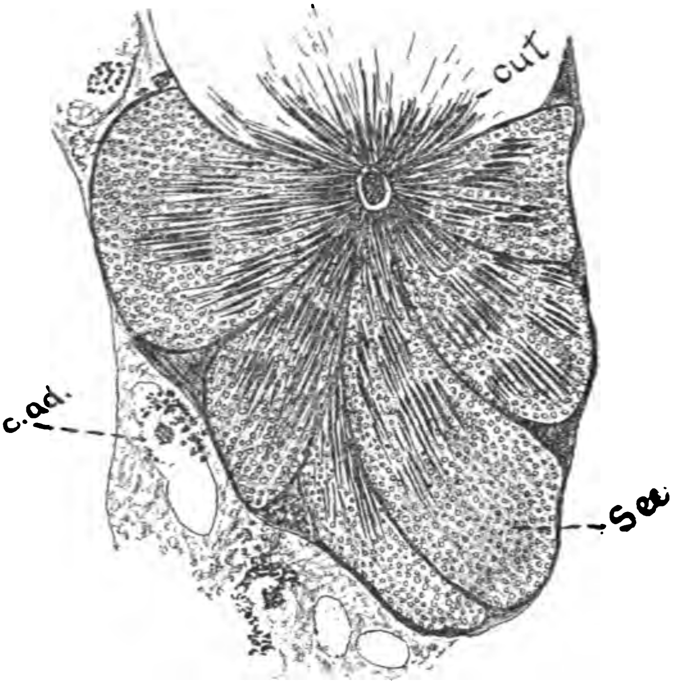

Fig. 16.
Section through a salivary gland of *Anopheles maculipennis* showing the location of the sporozoits. Redrawn from Grassi.

There is every reason to believe that malaria is carried over from one season to the next in the blood of man, and not in the mosquito. The cases of malaria which develop in winter are relapses of previous attacks; or, in rare instances, an infected *Anopheles* remains active in a warm room and bites at night, thus producing a new case of malaria.

There is good reason to believe that if every case of malaria could be completely cured and all plasmodia eradicated before the advent of another season, endemic malaria in temperate climes would become extinct in a single year.

It has been said on a previous page that the proof afforded by the development of the malarial organism in *Anopheles* and the infection of well persons by infected *Anopheles,* although absolutely convincing to the biologist, is not so to the lay mind. It was necessary that proof of another sort should be obtained, and this was done in a way as interesting as it was convincing.

In the Plain of Capaccio, Italy, Grassi (1901, p. 216), in 1900, made an experiment on a large scale. Ten cottages at the railway station of San Nicolo, Varco and Albanella were made mosquito-proof by carefully screening doors and windows. The doorways were provided with double screen doors. It may be stated, by the way, that the netting was of considerably smaller mesh than customary in this country. Of the 104 persons living in these ten cottages, all but eleven had previously lived in malarious regions; a majority had suffered from it during the previous season. The malarious season began each year about June 13th, according to the testimony of inhabitants of the district. This was confirmed by actual examination of a large number of *Anopheles.* None were found with sporozoits in their salivary (*i. e.,* poison) glands until June 14th. As early as March 25th vigorous efforts were begun to cure all who had malaria in their blood, the result of infection during the previous season. Grassi says: "The spectacle which these people presented before we began our treatment was the saddest imaginable; and those families who had lived in the place during the entire malarial season of the preceding year most strongly excited our sympathy." The "reconstitutions treatment" was not entirely successful, because begun too late. Even in June there were seven relapses of persons who had had malaria the previous season.

During the entire malarial season, from June 25th (when the first new case appeared in that region) till October 15th, the people in the protected houses enjoyed good health, notwithstanding they took no quinine. There were very few cases of sickness other than malaria, and five light cases of malaria, which soon disappeared, and all of which Grassi regarded as relapsing cases.

Of the 415 persons living in the immediate vicinity of the protected houses, every one had malaria during the season.

Another experiment made in the Roman Campagna—a district of most unsavory reputation for its terrible fevers—has been widely published.

In the latter part of the summer of 1900 two London doctors, Sambon and Low, erected a wooden cottage in the Campagna, near Ostia. The place selected was known to be one of the most malarious in the whole Campagna. The house was built so as to leave no chinks or crevices, and windows and doors were thoroughly screened. Drs. Sambon and Low lived here throughout the malaria season. They abstained from quinine, and took no precautions, except to be invariably within doors at sunset and not to go out until daylight. During the day they investigated the cases of human and cattle malaria in the neighboring villages and indoors conducted laboratory work. In short, they lived as people generally live, but were invariably indoors before the flight time of *Anopheles*. With the rains began the most dangerous part of the season. The natives of the region, having malaria in their systems, were pretty sure to come down with an attack at this time. The experimenters frequently went out in the rain and were wet through; but neither of them contracted malaria. The idea has everywhere prevailed that the night air is dangerous; but the well-screened windows of the cottage were left open night and day.

The objection may be made that *Anopheles* occur in many places where there is no malaria. This is perfectly true; but it does not prove that *Anopheles* is not the carrier of the disease. It only proves that the mosquitoes have had no opportunity to infect themselves by biting a malarious patient. A single person with malaria may start an epidemic in any *Anopheles* infested place.

Both from our knowledge of parasites of the class to which the malaria organism belongs and from the abundant experimental evidence we are justified in the conclusion that malaria is transmitted by mosquitoes of the genus *Anopheles,* and in no other way, save by the purely artificial method of inoculation of malarial blood.

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